State of the Environment Monitoring
Lake Rotorangi water quality and biological programme
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2018-2019

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Private Bag 713
STRATFORD

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Executive summary

Lake Rotorangi was formed in May 1984 by the construction of an earth fill dam on the Patea River for hydro-electric power generation. During the process of obtaining planning consents, it was recognised that, although a regionally significant recreational resource would be formed, considerable environmental impacts might also occur. Consequently, a comprehensive monitoring programme was developed and implemented for the lake. This report presents the results of the 29th year of this monitoring.

Four water quality sampling surveys were performed at two sites each during the 2018-2019 period. The first of the two sites surveyed is located in the mid reaches of the lake, while the second site is located nearer to the dam.

Changes in thermal stratification during the year in both periods were largely similar to that typically recorded in previous surveys of this reservoir-type lake. Thermal stratification was beginning to form at both sites during the spring survey, and was well developed during the late summer-autumn at the mid and lower lake sites, with dissolved oxygen depletion measured in the lower waters of the hypolimnion at both sites. Oxygen depletion remained evident in winter at the lower lake site. Lake overturn had not occurred completely at the lower lake site by the time of the winter survey, although water temperatures were uniform throughout the water column. These conditions have been typical of this reservoir-type lake on most occasions to date.

During the monitoring period, phytoplankton richnesses (diversity) were higher than typical, although coincident with low to moderate chlorophyll-a levels. The main limiting factors for phytoplankton communities within the lake probably continue to be plant nutrient availability and frequency of river freshes. A very sparse macroinvertebrate fauna has been found amongst the fine sediments of the deeper lake sites where only those taxa able to tolerate the lengthy periods of very low dissolved oxygen levels which have been recorded, are able to establish communities.

A macrophyte survey was not carried out during the period under review and is next scheduled for the 2020-2021 period. The autumn 2018 macrophyte survey identified the oxygen weed *Egeria densa* as the dominant macrophyte in the lower part of the lake. The other species recorded as dominant was *Ceratophyllum demersum* (hornwort), in parts of the mid-section of the lake. Hornwort, which was first recorded in the 2012 survey and had increased markedly at the time of the 2015 survey, was not recorded to have extended beyond the mid-section in the 2018 survey. It has been predicted that hornwort will eventually become dominant, out-competing *E. densa* and *L. major*. While this is not expected to cause significant impacts on the ecology of Lake Rotorangi or on the hydro-electric scheme, there is now greater potential for it to spread to nearby lakes, where such impacts could be much more severe, e.g. Lake Rotokare.

Lake condition, in terms of lake productivity, continued to be within the category of mesotrophic to possibly mildly eutrophic (mildly nutrient enriched). However, taking into account the influence of suspended sediment in this reservoir, and the moderately low chlorophyll levels, the classification is more appropriately mesotrophic. Previous trending of these water quality data over time found a very slow rate of increase in trophic level. Updated trend analysis, for the period 1990-2018, reconfirmed the rate of increase in trophic level is very slow and insignificant. Analysis also confirmed that the lake continues to be classified as mesotrophic in terms of biological condition.

The monitoring programme will continue in its present format for State of the Environment reporting purposes with regular (3-yearly) additional biological components (e.g. macrophyte survey) for consent compliance purposes. This report also includes recommendations for the 2019-2020 monitoring year.

Table of contents

List of tables

List of figures

1 Introduction

1.1 General

The *Resource Management Act 1991* ('the RMA') established new requirements for local authorities to undertake environmental monitoring. Section 35 of the RMA requires local authorities to monitor, among other things, the state of the environment of their region or district, to the extent that is appropriate to enable them to effectively carry out their functions under the Act.

To this effect, the Taranaki Regional Council (the Council) established a State of the Environment monitoring (SEM) programme for the region. This programme is outlined in the Council's 'State of the Environment Monitoring Procedures Document', which was prepared in 1997. The monitoring programme is based on the significant resource management issues that were identified in the Council's *Regional Policy Statement for Taranaki (1994a).*

The SEM programme comprises a number of individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). For these annual monitoring activities, summary reports are produced following the end of each monitoring year. Where possible, individual consent monitoring programmes have been integrated with the SEM programme to save duplication of effort and minimise costs (as in the case of the TrustPower Ltd. Patea Dam HEP programme in the past). The purpose of annual SEM reports is to summarise monitoring activity results for the year and provide a brief interpretation of these results.

Annual SEM reports act as 'building blocks' towards the preparation of the regional state of the environment report every five years. The Council's first, or baseline, SEM report was prepared in 1996 (TRC, 1996a), summarising the region's progress in managing environmental quality in Taranaki over the past two decades. The second report (for the period 1995-2000) was published in 2003 (TRC, 2003a). The third SEM report (for the period 1995 to 2007) was published in 2009 (TRC, 2009a) and included trend reporting. The fourth report (for the period 1995 to 2013) was published in 2015 (TRC, 2015a). The provision of appropriate statistical software now allows regular reporting on trends in environmental quality over time where there has been an accumulation of a comprehensive dataset of sufficient duration to permit a meaningful analysis to be undertaken (i.e. minimum of 10 years).

1.2 Lake Rotorangi and catchment

Lake Rotorangi was formed in May 1984 by the construction of an earth fill dam on the Patea River. The dam was integral to a power scheme designed to harness the flow of the Patea River and produce sufficient power for Egmont Electricity to meet approximately 60% of its consumer needs. During the process of obtaining planning consents, it was recognised that, although a regionally significant recreational resource would be formed, considerable environmental impacts might also occur. Consequently, when planning and water right consents were granted, specific conditions were imposed upon water rights, which involved monitoring and otherwise studying the effects of the scheme on the environment, for the protection of the public interest.

The appearance of Lake Rotorangi, its biological value, and its suitability for a range of recreational and commercial uses is directly related to lake water quality. Water quality management is therefore the key to the continued success of the lake and environs as regional and national recreational resources. Consequently, all lake management decisions and lake uses need to be undertaken in consideration of maintaining good lake water quality conditions.

The Patea Catchment above the dam (including the Mangaehu sub catchment) covers an area of 86,944.3 ha, including an urban area of 840.9 ha (1%). Riparian plans have been prepared for an area of

19,466 ha[1] (25% of catchment). As of June 2019, some 235 riparian plans have been prepared by the Council in relation to properties within the Patea River sub-catchment. No additional plans have been produced for properties in the Mangaehu River sub-catchment, upstream of the lake during the period under review. Within these plans, some 1008 km of Patea riverbank [71% of the total banks' length] and 26 km of Mangaehu stream banks [54%] currently have adequate riparian protection provided on the properties covered by the plans. This represents an increase of 143 km in the Patea catchment and 7 km in the Mangaehu catchment over the past three years. Outside of the properties covered by riparian plans, there are a further 51% and 98% of streambanks in the Patea and Mangaehu catchments respectively, with only some (natural) degree of riparian protection or landowner fencing/planting that is not covered by a Council-prepared riparian plan. Within the Lake Rotorangi catchment area, 43233 ha (50%) is covered by Council Hill Country plans, addressing land management and sediment issues. This area is dominated by dry stock properties, as well as 6,588.7 ha (8%) of DOC owned land, and is located to the northeast and south east of the catchment.

1.3 Historic monitoring of Lake Rotorangi

The initial sampling programme was designed to keep a watching brief on lake water quality and productivity trends, in order to assess the way in which the new lake was settling down and its overall environmental consequences. The results of this intensive monitoring programme were published in the 'Lake Rotorangi - Monitoring a New Hydro Lake' (Taranaki Catchment Board, 1988) report.

The initial monitoring of the lake indicated that the lake was not grossly eutrophic as was initially predicted, but mildly eutrophic or mesotrophic. The initial monitoring also determined that the annual thermal stratification cycle, which the lake undergoes, is the single most important factor influencing the overall water quality and biological productivity trends within the lake. The formation of a stable stratified lake during the spring/summer period is dependent upon seasonal ambient temperature changes. Stratification gives rise to a physical barrier, separating the surface water body (epilimnion) from the bottom water body (hypolimnion). The intermediate zone is known as the metalimnion. The characteristics of lakes and the importance of nutrients and eutrophication were fully discussed in the Taranaki Catchment Board (1988) report.

Following the publication of the initial monitoring report, the Taranaki Catchment Board, in conjunction with the Egmont Electric Power Board, considered the frequency and nature of the future monitoring programme for Lake Rotorangi. Given the unexpectedly favourable way in which the lake had settled down, it was decided that the monitoring programme should be scaled down to a residual level involving less frequent sampling, yet be capable of maintaining an on-going measure of lake conditions. These scaled-down programmes have now operated since 1988 and have been the subject of twenty-seven Annual Reports and four subsequent state of the environment reports.

There was concern for the impact that larger flood events could have on the lake during the summer stratification period. The original intensive monitoring period (1984 to 1988) had been conspicuous for the absence of any large flood events entering the lake during such periods. However, the large floods of March 1990 and June 2015 provided some information in this respect (TRC, 1990, TRC 2016). The impacts of minor freshes have been reported from time-to-time (TRC 1992a; TRC 1993; TRC 1995).

In 1995, NIWA reviewed the appropriateness of the Lake Rotorangi monitoring programme and analysed all data collected during the last seven years of monitoring. Only minor changes to the monitoring programme were suggested (Burns, 1995). More details of the suggested changes are provided in Section 1.4. In 1999,

[1] Methodology used to calculate the area covered by plans has changed, resulting in a decrease in the reported area from 22048 ha in June 2018 to 19466 ha in June 2019

water quality data from Lake Rotorangi was assessed by Lakes Consultancy to determine the trophic status of the lake after ten years of monitoring (Burns, 1999). See Section 1.4 for further details. Lakes Consultancy also analysed Lake Rotorangi water quality data collected between 1990 and 2006 for trends to inform the consent renewal process which took place between 2007 and 2010 (Burns, 2006). See Section 1.4 for further details of both analyses undertaken by Lakes Consulting. The Council has analysed water quality trends since 2006, including the period 1990-2018 analysed for this report.

1.4 Trends in lake water quality

In 1995, the Council provided several years' (1988-1995) of Lake Rotorangi monitoring results and water quality reports to NIWA for in-depth lake water quality trend analysis. NIWA concluded that Lake Rotorangi had riverine qualities (such as the potential to be substantially affected by flood events). Consequently, it was deemed unnecessary to de-seasonalise data before conducting trend analysis on water quality over time. Further analysis indicated the lake had remained in a mesotrophic condition (Burns, 1995).

Minor changes to the existing Lake Rotorangi monitoring programme were recommended by NIWA in 1995 (Burns, 1995). Recommendations included the standardisation of sampling events to the current four dates to allow for the additional analysis of data and to provide better statistical power and robustness when determining changes in the lake's trophic condition. These changes were incorporated into subsequent monitoring programmes from 1996 onwards.

In 1999, the trophic status of Lake Rotorangi was reviewed based upon a lengthier period (ten years) of monitoring data (Burns, 1999 and Burns et al., 2000) employing analysis methods detailed in Burns and Rutherford (1998). The review indicated that, while the trophic level in Lake Rotorangi had not changed since monitoring commenced in 1988, the physical and chemical characteristics of the lake changed between upstream and downstream sampling sites. The report stated that the lake at the upstream site (L1) was basically riverine in character, while the lake near the dam had the characteristics of a mesotrophic lake containing surplus nitrate, but with phytoplankton growth limited by phosphorus availability. Hypolimnetic anoxic conditions were frequently encountered at site L2 (half way along the lake) and occasionally at site L3. However, there was little evidence of phosphorus release from the lake-bed sediments into the water column via anoxic regeneration.

The analysis of water quality trends over the period 1990-2006 indicated that the lake remained mesotrophic, although there had been a very slow increase in trophic level (Burns, 2006). The elevated trophic level indices were influenced by high turbidity values (caused by fine suspended sediment characteristic of this lake) and were not a true indication of the lake's actual trophic status. Burns concluded that 'despite the apparently very slow rate of change in trophic level, the lake would benefit from increased riparian management initiatives in the upstream catchment.'

The Council has continued to analyse water quality trends since 2006, including the period 1990-2018 (last 27 years) analysed for this report. The analysis methodology is based on that employed by Burns (2006). The most recent analysis continues to support the conclusions of Burns (2006) and indicates the trophic level continues to increase at a very small, insignificant annual rate of change (0.02 ± 0.01 TLI units per year). Trend analysis of the key water quality variables (chlorophyll-a, secchi disc, total phosphorus and total nitrogen) showed that chlorophyll-a was increasing over time (albeit at a slow rate of change within the mesotrophic level range). Nitrate was also increasing over time.

1.5 Monitoring programme

The Lake Rotorangi monitoring programme consists of two primary components; physicochemical sampling and biological sampling. These components are detailed in the sub-sections below.

1.5.1 Lake Rotorangi physicochemical sampling

In 2018-2019, the Council undertook sampling of the lake at two sites (L2 and L3) on four occasions designed to coincide with varying stratification stages within the lake. The analytical parameters measured followed the Council's standard lake sampling protocols at intervals and sites determined by the agreed programme. The upper (riverine) site was removed from the programme during the 2010-2011 period as it was not considered to be a representative lake site as required for future lake monitoring and state of the environment trending requirements.

1.5.2 Lake Rotorangi biological monitoring

Phytoplankton monitoring was performed at the same two sites sampled for physicochemical analysis, on all four of the lake sampling visits each year. Macroinvertebrate samples collected from the lake bed at these two sites during the spring physicochemical survey are a triennial component of the programme and were last collected in 2017. The aquatic macrophyte survey of the lake is also a triennial component of the monitoring programme and was last performed during autumn 2018. The macroinvertebrate survey is next due in spring 2020, while the macrophyte survey is next due in autumn 2021.

1.6 Objective

The objective of this Report is to provide an assessment of the physicochemical and biological state and trends in Lake Rotorangi. Findings reported here will be used to inform on consent compliance reporting for Lake Rotorangi and to assist with the management of Lake Rotorangi, general environmental management policy and plans for regional lakes.

2 Water quality monitoring

2.1 Methods

The water quality physicochemical monitoring programme for Lake Rotorangi consisted principally of four sampling surveys each year timed to coincide with:

a. pre-stratification period (spring) conditions (near 20 October);

b. stable summer stratification conditions (near 20 February);

c. pre-overturn (later summer) conditions (within one month of (b), and near 20 March); and

d. post-overturn winter conditions (near 20 June).

The parameters measured at the two lake sites during each sampling survey are listed in Table 1 and the locations of routine lake sampling sites are shown in Figure 1.

Table 1 Water quality parameters measured at the two sampling sites

Parameter	Sampling site	
	Lake Site 2	Lake Site 3
GPS location **General site code**	**1729856E 5626435N** **LRT 000300**	**1734948E 5621974N** **LRT 000450**
Depth profile[1] for		
- dissolved oxygen	X	X
- temperature	X	X
Point source[2] in the:		
(a) Surface, for	[LRT00S300]	[LRT00S450]
- secchi disc transparency	X	X
- black disc transparency	X	X
- pH	X	X
- conductivity	X	X
- turbidity	X	X
- suspended solids	X	X
- chlorophyll-a[3]	X	X
- *E. coli*	X	X
(b) Epilimnion, and	[LRT00E300]	[LRT00E450]
(c) Hypolimnion, for	[LRT00H300]	[LRT00H450]
- suspended solids	X	X
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrate-nitrogen	X	X
- nitrite-nitrogen	X	X
- ammoniacal-nitrogen	X	X
- total Kjeldahl nitrogen	X	X
- total nitrogen	X	X
- pH	X	X
- conductivity	X	X
- turbidity	X	X
(d) Sediment/water/interface[4], for	[LRT00B300]	[LRT00B450]
- ammoniacal-nitrogen	X	X
- total phosphorus	X	X
- dissolved reactive phosphorus	X	X
- nitrite and nitrate nitrogen	X	X
- pH	X	X
- turbidity	X	X

Note:
[1] *Depth profile sampling refers to taking discrete depth measurements*
[2] *Point source sampling refers to taking samples which reflect the water quality of a specific zone*
[3] *Chlorophyll-a collected through a column (= 2.5 x secchi disc transparency) ie depth integrated (at sites LRT00P300 & LRTOOP450)*
[4] *February and March only*

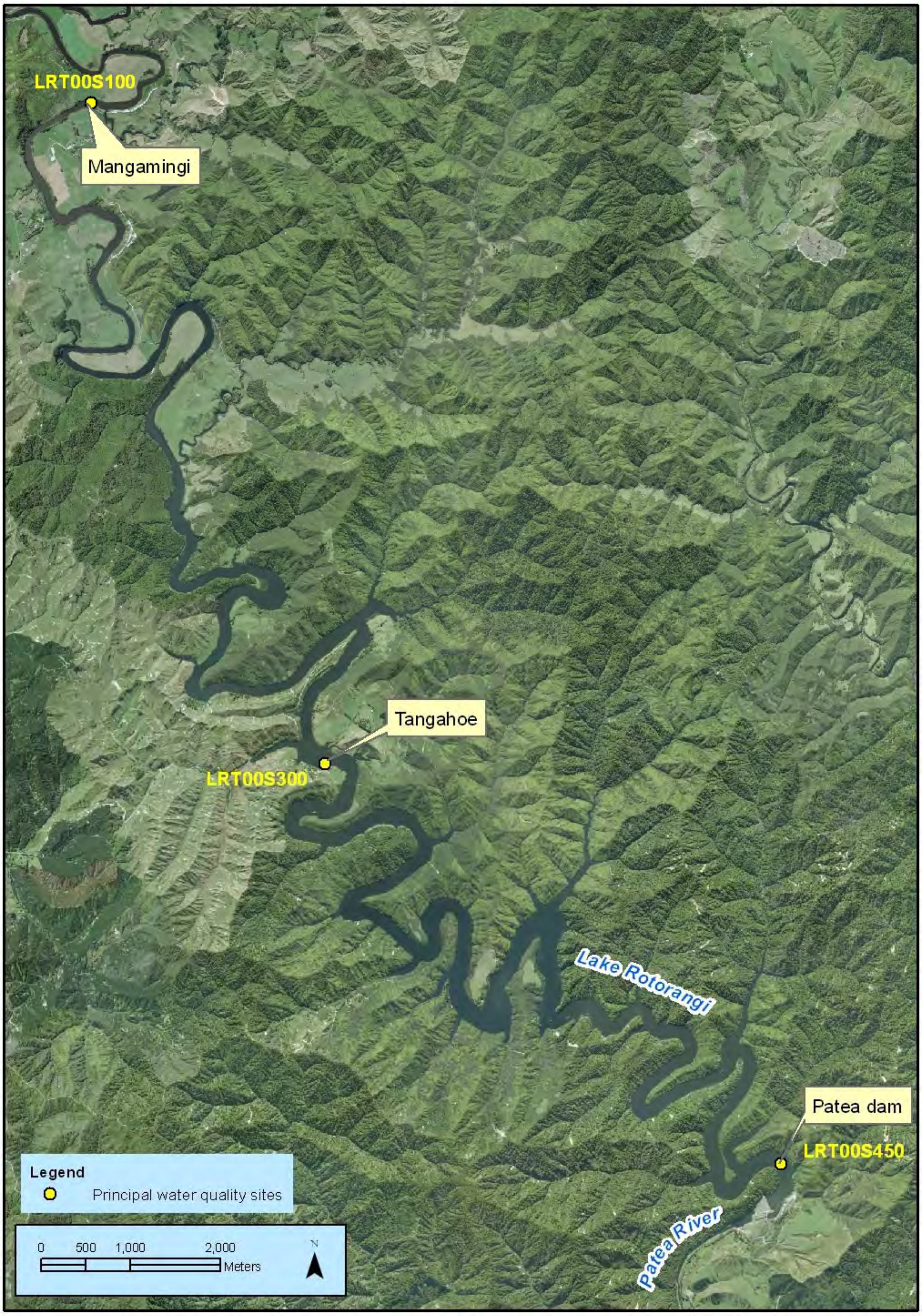

Figure 1 Aerial location map of Lake Rotorangi water quality sampling sites for 2018-2019 (LRT000300 and LRT000450)

In the year under review, the sampling runs were performed at the established monitoring sites on the dates shown in Table 2.

Table 2 Sampling dates for the Lake Rotorangi water quality monitoring programme

Sampling Run	Time	Date
1	Spring	24 October 2018
2	Late summer, stratification	20 February 2019
3	Autumn, stratification	19 March 2019
4	Winter	19 June 2019

The spring sampling survey was performed under steady fresh recession river flow conditions following a period of two small freshes in the Patea catchment and three small freshes in the Mangaehu catchment over the preceding month (Appendix I). The late summer survey occurred under steady low flow conditions during a dry period of over a month prior in both catchments. The autumn survey was performed under steady fresh recession flow conditions five days since a small fresh in the Mangaehu catchment and eleven days after a small fresh in the Patea catchment, preceded by a dry period of three weeks. The final (winter) survey was performed during river recession flow conditions, thirteen days after a small fresh and twenty days after a moderate fresh. There were a further two moderate freshes in each of the two catchments during the preceding six weeks. Lake level was moderate at the time of the spring (75.9 m asl), summer (76.1 m asl), autumn (76.7 m asl) and winter (76.0 m asl) surveys.

Flow data for the Patea River and Mangaehu River are presented in Appendix I, while the synthesised inflow to Lake Rotorangi is shown in Figure 2. This synthetic flow is the flow entering the head of the lake (at Mangamingi) and equates to flows from the Patea River and Mangaehu River catchments above Mangamingi.

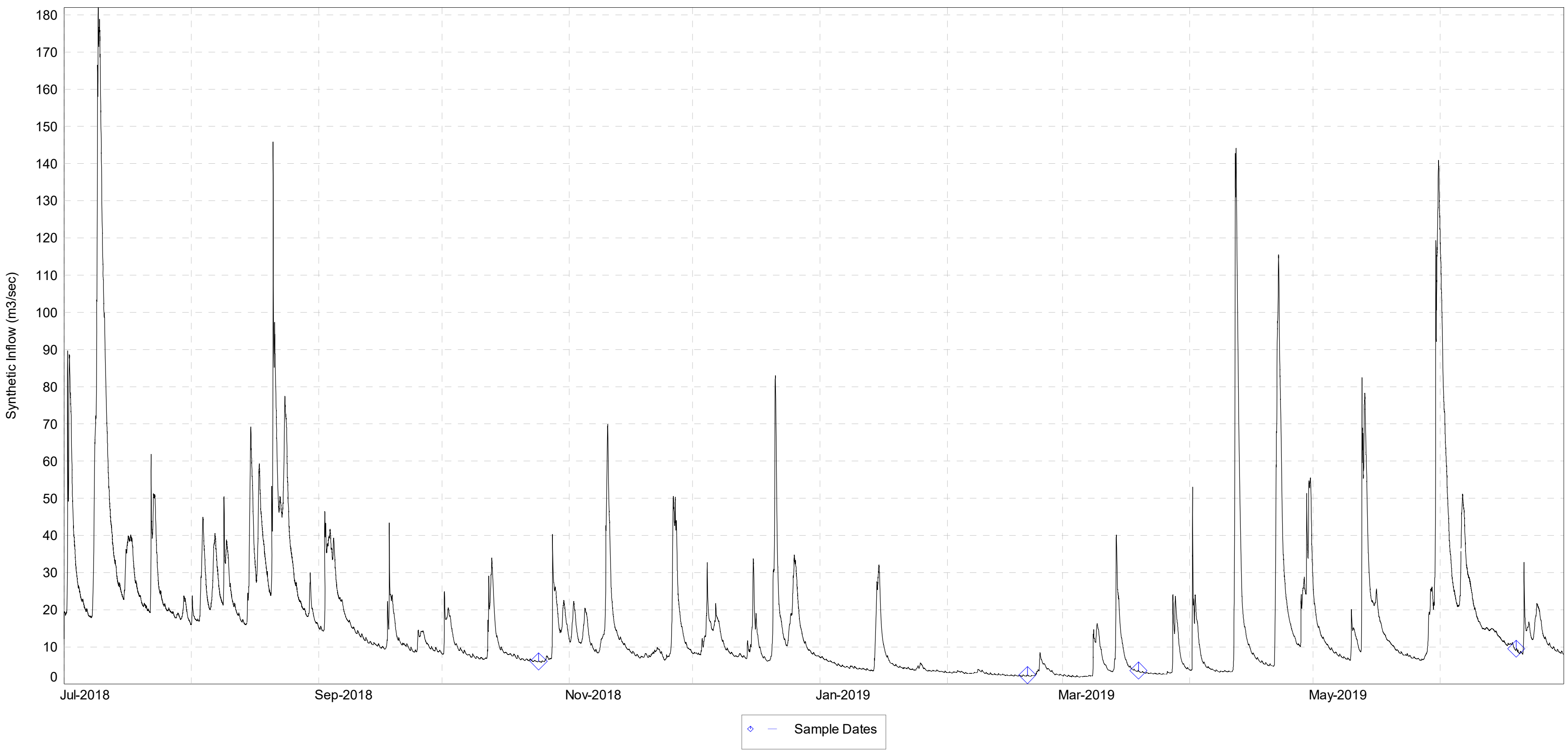

Figure 2 Synthetic inflow at Lake Rotorangi for the period 1 July 2018 to 30 June 2019

3 Results

3.1 General observations

Information recorded at each site on the four sampling occasions in 2018-2019 is summarised in Table 3. This information is collected in conjunction with physicochemical sampling data as a component of the monitoring programme. Lake conditions reflected the preceding river flow conditions referenced in Section 2.1.

Table 3 Observations at Lake Rotorangi monitoring sites on each sampling date during 2018-2019

Site	Date	Time	Weather	Wind	Air Temp	Surface Water Temp	Lake Appearance	Secchi Disc transparency	Black Disc transparency	Lake depth at sampling site
Unit		(NZST)			(°C)	(°C)		(m)	(m)	(m)
L2	24 Oct 2018	0913	Overcast, fine	Calm	14.4	17.7	Slightly turbid, brown; surface flat; no debris noted	3.02	1.66	38.4
	20 Feb 2019	0930	Scattered cloud, fine	Calm	22.4	23.1	Slightly turbid, dark brown; surface flat; no debris noted	4.32	2.99	38.4
	19 Mar 2019	0906	Scattered cloud, fine	Light breeze	18.2	22.2	Clear, brown; surface rippled; no debris noted	3.58	2.71	39.6
	19 Jun 2019	1012	Overcast, fine	Calm	4.4	11.3	Slightly turbid, brown, surface flat; no debris noted	2.19	1.68	38
L3	24 Oct 2018	1103	Overcast, fine	Calm	16.3	17.4	Slightly turbid, brown; no debris noted	4.21	2.4	51.5
	20 Feb 2019	1215	Scattered cloud, fine	Light breeze	29.4	24.3	Slightly turbid, dark brown; surface rippled; no debris noted	4.63	4.32	52.8
	19 Mar 2019	1103	Scattered cloud, fine	Calm	24.3	22.5	Clear, brown; surface rippled; no debris noted	5.08	3.7	52
	19 Jun 2019	1201	Fine	Calm	11.8	11.9	Slightly turbid, brown, surface flat; no debris noted	3.88	2.9	50.1

3.1.1 Thermal stratification

A summary of historical water temperature data is provided in Table 4.

Table 4 Statistical summary of surface water temperature data from June 1990 to June 2018

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Temperature	°C	9.6	23.9	17.2	110
L3 surface	Temperature	°C	9.5	24.6	17.9	110

The two lake sites (L2 and L3) continued to exhibit varying degrees of thermal stratification during the monitoring period (Figure 3), typical of the majority of past years' stratification patterns. Temperatures measured in the surface and bottom waters at each lake site during the period under review are compared with historical monthly averages in Table 5.

Table 5 Surface and bottom waters temperatures at each Lake Rotorangi site during the period under review

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2018	17.7 (14.8)	9.4 (9.0)	17.4 (15.0)	9.1 (8.7)
February 2019	23.1 (21.9)	9.6 (9.6)	24.3 (22.1)	9.2 (9.4)
March 2019	22.2 (19.5)	9.6 (9.8)	22.5 (19.8)	9.3 (9.6)
June 2019	11.3 (11.2)	9.7 (9.5)	11.9 (11.3)	9.4 (9.5)

Note: ( ) = average monthly temperature for period 1984 to mid-2018

Results from the 2018-2019 survey indicated surface water temperatures at both sites were within range of historical measurements (Table 4). The temperatures recorded in February 2019 were within 0.3˚C to 0.8˚C of the maximum temperatures, recorded in February 1994 at a similar time of day.

At site L2, temperatures recorded over 2018-2019 were within 0.1˚C to 2.9˚C of averages calculated for individual sampling months. At site L3, temperatures were within 0.6˚C to 2.7˚C of individual monthly averages.

Temperatures at the bottom of the water column recorded over 2018-2019 at both sites were 1.6°C to 2.5°C lower than surface water temperatures in winter. In late summer, differences between bottom and surface water temperatures increased to 13.5°C to 15.1˚C. However, these temperatures were within 0.4˚C of average temperatures calculated for corresponding sampling months throughout most of the year. Bottom water temperatures at both sites showed a narrow range of just 0.3˚C due to minimal mixing throughout the year. Surface water temperature ranges were much wider (11.8°C [L2] to 12.4°C [L3]).

Water temperature and dissolved oxygen profiles recorded on each sampling occasion during 2018-2019 at each site are illustrated in Figure 3. Partial thermal stratification was recorded at sites L2 and L3 at the time of the October 2018 survey, while both the February 2019 and March 2019 surveys illustrated more well-established thermal stratification. The location of the thermocline during summer-autumn was between 5 m and 9 m below the lake surface at site L2, and 5 to 8 m at site L3. By the June 2019 survey, the thermal stratification had overturned, due to the cooling of epilimnetic waters and the occurrence of several significant river freshes to Lake Rotorangi during the autumn and winter of 2019. However, strong dissolved oxygen stratification remained at site L3 (see Section 3.1.2), a similar situation to that monitored in many previous years.

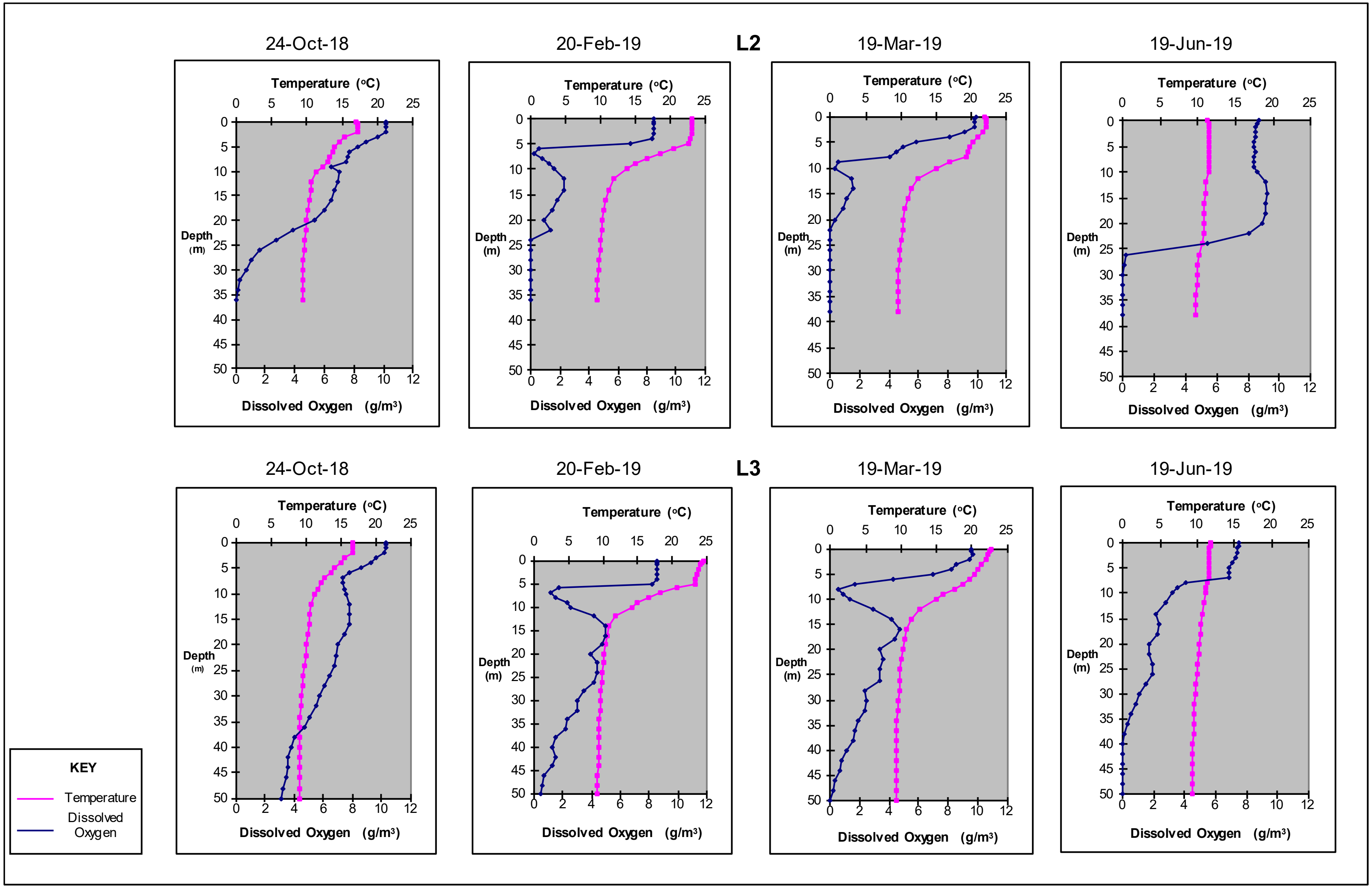

Figure 3 Temperature (°C) and dissolved oxygen (g/m^3) profiles for sites L2 and L3, 2018-2019

3.1.2 Dissolved oxygen stratification

A summary of historical dissolved oxygen data is provided in Table 6.

Table 6 Statistical summary of dissolved oxygen data from June 1990 to June 2018

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 surface	Dissolved oxygen	g/m^3	6.8	11.1	8.9	110
	Dissolved oxygen saturation	%	68	116	92	110
L3 surface	Dissolved oxygen	g/m^3	3.6	11.0	8.8	110
	Dissolved oxygen saturation	%	34	116	95	110

Table 7 Temporal changes in percentage dissolved oxygen saturation in surface and bottom waters at each Lake Rotorangi site during the period under review

Sites	L2		L3	
Date	Surface	Bottom	Surface	Bottom
October 2018	105 (95)	7 (27)	97 (98)	15 (33)
February 2019	99 (99)	0 (2)	103 (101)	1 (7)
March 2019	112 (93)	0 (4)	111 (94)	0 (7)
June 2019	79 (81)	0 (55)	70 (66)	0 (13)

Note: ( ) = average monthly saturation for period 1984 to mid-2018

Surface water percentage dissolved oxygen saturation levels were within past ranges at both sites during the 2018-2019 monitoring year (Table 7). Levels varied in relation to average saturation levels recorded from previous monitoring surveys for the four relevant months. Surface saturation levels were either within 3% of total saturation, or were supersaturated, with the exception of the winter. Partial mixing of the more saturated surface waters with the less saturated hypolimnetic water was recorded by June 2019, as indicated by the decrease in percentage saturation to well below 100% saturation.

The oxygen saturation level in hypolimnetic water of Lake Rotorangi varied according to the degree of stratification established at the time of sampling. Oxygen consumed by either biological or chemical processes cannot be replaced due to thermal separation from the more oxygenated surface waters. This causes oxygen depletion in the hypolimnion unless re-mixing occurs, either as a result of natural overturn processes or as a result of flood events in the river inflow.

In the period under review, there were lengthy periods of dissolved oxygen reduction in the hypolimnion at both sites L2 and L3 (Figure 3), although a lesser degree of oxygen stratification was recorded at site L3 in October 2018. Strong dissolved oxygen stratification remained at both sites in the June 2019 survey, despite both sites being isothermal at this time. These results are typical of those recorded in Lake Rotorangi in the past 25 years.

During the late summer-autumn period, anoxic conditions (i.e. dissolved oxygen concentrations less than 0.5 g/m^3) were recorded at depths below 25 m at site L2, and below 45 m at site L3. Some depletion was found at site L2 in spring, below a depth of 30 m.

Data from both the temperature and dissolved oxygen profiles at sites L2 and L3 for each of the February/March periods to date have been used to calculate the gross volumetric hypolimnetic oxygen depletion rate (VHOD) and the area hypolimnetic oxygen depletion rate (AHOD) (Rutherford, 1982; Vant

1987). Due to destruction of stratification by extensive February 2004 flooding, these rates could not be determined for the 2003-2004 period, and partial destruction by frequent freshes in March 2012 affected calculations for the 2011-2012 period, particularly at site L2. Calculated VHOD results are presented in Appendix II. However, due to a number of shortcomings in the calculation method, along with calculations introduced due to the unique setting and nature of Lake Rotorangi, we do not provide an overall analysis of the data or any trends.

The main shortcoming of the calculation method is that annual VHOD rates are calculated by regression. Currently, the February and March sampling provide only two data points to form the basis of this regression. Ideally a regression analysis should be carried out on a minimum of three data points. Furthermore, the calculation of VHOD requires that data points be no further than a month apart. Therefore, increased sampling effort during the stratified period would be required during the stratified period to increase the reliability of the annual VHOD regression.

In addition to the drawbacks in the sampling and calculation methodologies, reservations about the appropriateness of the VHOD method, given the nature of Lake Rotorangi, have been noted in previous reports (eg. Taranaki Catchment Board, 1988 and 1989). In particular, Burns (1995) noted that the average hypolimnion temperature in the lake often decreased over the duration of the stratified period, whereas in most lakes the hypolimnion temperature increases over this period. The decreasing temperature means that it is not possible to calculate the rate of re-oxygenation which occurs when the hypolimnion is warmed by downward mixing of thermocline water. The observed drop in hypolimnion temperature may be due to the inflow of cooler water into the top levels of the hypolimnion or be the result of the hypolimnetic withdrawal of water for power generation, although the latter is relatively unlikely. Whatever the driving mechanism, the observation of decreasing hypolimnion temperatures indicates that the water mass being monitored has changed, and thus largely invalidates any reliable calculation of dissolved oxygen depletion rates.

Furthermore, it has been noted that dissolved oxygen values close to the lake bottom are often near zero in February and March, invalidating the calculated oxygen depletion rates. Depletion rates should not be calculated when oxygen concentrations drop below 2 g/m^3, as rates become concentration-dependent below this concentration (Burns 1995). While analysis of VHOD has continued in the past despite these limitations, Burns (2006) noted that the calculated VHOD rates show high variability over the 1990-2006 period. This could be due to vertical turbulence (provided by wide ranges of inflows) given the reservoir-type lake system. As a result, the calculated rates are unlikely to provide useful trend information (see Figures in Appendix II).

3.1.3 Secchi disc transparency/suspended solids

Summary statistics for Lake Rotorangi physical water quality data from 1990 to June 2018 is provided in Table 8.

Table 8 Statistical summary of physical water quality data from 1990 to June 2018

Location	Parameter	Unit	Minimum	Maximum	Median	N
L2 Surface	Secchi disc transparency	m	0.09	5.23	2.72	110
	Black disc transparency	m	0.09	4.50	1.82	103
	Turbidity	NTU	0.4	240	1.7	96
	Suspended solids	g/m^3	<2	170	2	103
	Conductivity @ 25°C	µS/cm	59	165	119	90
L2 Epilimnion	Turbidity	NTU	0.6	250	2.3	101
	Suspended solids	g/m^3	<2	180	2	107
	Conductivity @ 25°C	µS/cm	58	160	120	105
L2 Hypolimnion	Turbidity	NTU	1.6	510	5.4	103
	Suspended solids	g/m^3	<2	340	3	109
	Conductivity @ 25°C	µS/cm	64	149	118	107
L3 Surface	Secchi disc transparency	m	0.12	7.0	3.12	110
	Black disc transparency	m	0.12	5.25	2.6	95
	Turbidity	NTU	0.4	250	1.3	99
	Suspended solids	g/m^3	<2	170	<2	104
	Conductivity @ 25°C	µS/cm	68	167	116	94
L3 Epilimnion	Turbidity	NTU	0.4	250	1.6	101
	Suspended solids	g/m^3	<2	170	2	109
	Conductivity @ 25°C	µS/cm	68	165	117	105
L3 Hypolimnion	Turbidity	NTU	0.7	780	3.2	103
	Suspended solids	g/m^3	<2	500	<2	111
	Conductivity @ 25°C	µS/cm	68	136	112	107

Notes: 1) Turbidimeter changed from Hach 2100A to Cyberscan WTW in June 2005, then to Hach 2100N in June 2018.
2) Conductivity units have changed from mS/m @ 20°C to µS/cm @ 25°C. Previously reported values have been converted to the new standard unit, resulting in an approximately 11-fold increase.

Data recorded from both sites during the 2018-2019 year (Table 9) were within previously recorded ranges. Suspended solids remained below the detection limit for the entire period under review. It should be noted that a change in laboratory provider in June 2018 increased the suspended solids detection limit from <2 g/m^3 to <3 g/m^3, and that median historical suspended solids for all sites are lower than the new detection limit.

Table 9 Physical water quality monitoring data for the two Lake Rotorangi sites in the 2018-2019 period

	Sites		L2			L3		
Date	Parameter	Unit	S	E	H	S	E	H
24 Oct 2018	Secchi disc	m	3.02	-	-	4.21	-	-
	Black disc	m	1.66	-	-	2.40	-	-
	Turbidity	NTU	1.05	1.23	2.7	1.00	1.09	3.3
	Suspended solids	g/m³	<3	<3	<3	<3	<3	<3
	Conductivity @ 25°C	µS/cm	138	138	113	134	134	105
20 Feb 2019	Secchi disc	m	4.32	-	-	4.63	-	-
	Black disc	m	2.99	-	-	4.32	-	-
	Turbidity	NTU	1.52	1.04	2.4	0.54	0.69	1.83
	Suspended solids	g/m³	<3	<3	<3	<3	<3	<3
	Conductivity @ 25°C	µS/cm	155	154	121	132	132	108
19 Mar 2019	Secchi disc	m	3.58	-	-	5.08	-	-
	Black disc	m	2.71	-	-	3.70	-	-
	Turbidity	NTU	0.69	1.88	2.2	0.66	0.93	1.32
	Suspended solids	g/m³	<3	<3	<3	<3	<3	<3
	Conductivity @ 25°C	µS/cm	164	180	123	140	142	109
19 Jun 2019	Secchi disc	m	2.19	-	-	3.88	-	-
	Black disc	m	1.68	-	-	2.90	-	-
	Turbidity	NTU	2.8	2.3	8.9	1.43	1.28	1.24
	Suspended solids	g/m³	<3	<3	<3	<3	<3	<3
	Conductivity @ 25°C	µS/cm	111	111	126	130	129	110

Note: [Sites: S = surface; E = epilimnion; H = hypolimnion]

Secchi disc measurements (an estimate of vertical water clarity) in 2018-2019 were greater than median values, with the exception of those recorded in June 2019. Surface turbidities showed the same pattern, reflecting the proximity to a fresh as baseflow was not reached prior to the June 2019 survey (Figure 2). Turbidity was also below median in the epilimnion and hypolimnion thoughout the year, except at site L2 in the June 2019 survey. Secchi disc and conductivity recorded a narrower range at site L3 than at L2 during the period under review.

Black disc measurements (Table 3) provide an estimate of horizontal water clarity. Black disc observations in conjunction with vertical (Secchi disc) readings provide information on the penetration of diffuse light into water. A correlation between Secchi disc and black disc transparencies has been prepared for both of the sampling sites (Figure 4). This indicates that a direct relationship exists between the two transparency readings, as might be expected, and that while in general Secchi disc (vertical) clarity has been slightly greater than black disc (horizontal) clarity at both sites (by a ratio of about 1.2:1), the two transparencies' values are more similar further down the lake, i.e. where the river influence is less pronounced.

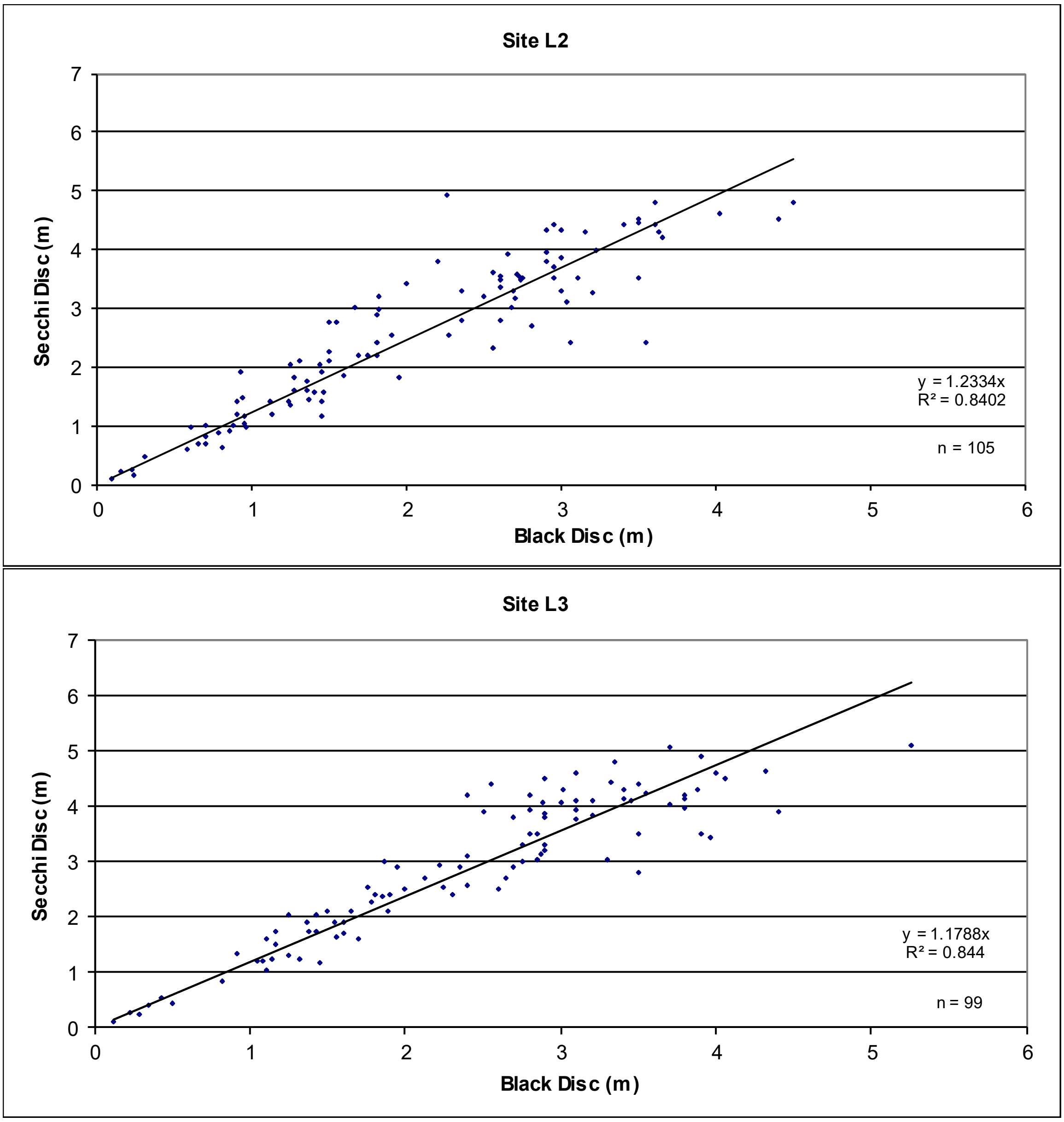

Figure 4 Relationship between Secchi and black disc transparency at each sampling site

These trends have continued to be recorded during the most recent monitoring period under a moderate range of clarities.

3.1.4 Biological productivity

Primary productivity is indicated by chlorophyll-a concentrations (Pridmore, 1987). The summary statistics for chlorophyll-a data collected between 1990 and June 2018 are provided in Table 10, while results from the 2018-19 monitoring programme are presented in Table 11.

Table 10 Statistical summary of chlorophyll-a data from 1990 to June 2018

Location	Parameter	Unit	Minimum	Maximum	Median	Mean	N
L2 photic zone	Chlorophyll-a	mg/m^3	<1.0	13.9	2.8	3.3	109
L3 photic zone	Chlorophyll-a	mg/m^3	<1.0	13.4	2.3	3.4	109

A change in laboratory provider in June 2018 has resulted in increased variability in the detection limit for the (same) chlorophyll-a analysis. Since this time, the detection limit has increased from <1 mg/m^3, to <3 mg/m^3 and <5 mg/m^3 for two samples, and has also decreased from <1 mg/m^3 for one sample.

Table 11 Chlorophyll-a concentrations (mg/m^3) (including historical monthly means) for the Lake Rotorangi sites

Month	Sites			
	L2		L3	
	Mean (1984-2018)	Result 2018-19	Mean (1984-2018)	Result 2018-19
October	3.5	3.5	4.2	2.8
February	3.7	3.7	3.1	2.6
March	4.1	2.8	4.4	3.0
June	1.8	1.1	1.5	0.9
Annual Range: 2018-2019	-	1.1-3.7	-	0.9-3.0
Historical Range: 1984-2018	-	<1-13.9	-	<1-15

All chlorophyll-a concentrations measured at the two sites during the 2018-2019 period were within past ranges (Table 10) found by surveys since 1990. The concentrations during the period under review were lower than or equal to historical seasonal means (Table 11). Recorded concentrations were higher than historical medians except in the winter survey.

Maximum lake chlorophyll-a concentrations have tended to be measured during late summer or autumn at sites L2 and L3. Over the 2018-2019 period, the highest concentrations were found in the photic zone of the mid lake (L2) in summer and in the lower lake (L3) in autumn. All measured concentrations were within previous ranges recorded since 1984 (Table 11). The maximum chlorophyll-a concentration of 3.7 mg/m^3 was measured at site L2 during the late summer period and was only 0.7 mg/m^3 higher than the concentration found at site L3 in autumn.

In terms of broad guidelines listed in Pridmore (1987) for maximum and annual mean chlorophyll-a concentrations, the lake would continue to be most likely categorised as mesotrophic. This categorisation is consistent with the conclusions of Burns (1995, 1999, and 2006). However, these guidelines should be used with caution due to the variability of the sample monitoring particularly in earlier years and the riverine nature of this lake. It should also be emphasised that chlorophyll-a measurements are only partial indications of trophic state. Determination of trophic condition requires examinations of a number of diverse criteria, particularly nutrients, clarity, and chlorophyll-a (see Burns, 1999, Burns, 2006 and Appendix II).

3.1.4.1 Nutrients

A summary of historical nutrients data is provided in Table 12, with water quality data relating to nutrient species, measured during the monitoring period, summarised for each site in Table 13 to Table 16. The results are discussed in relation to the epilimnion and hypolimnion of the lake.

Table 12 Statistical summary of nutrients data from 1990 to June 2018

Site	Parameter	Unit	Minimum	Maximum	Median	No. of samples
L2 Epilimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.018	0.005	109
	Total phosphorus	g/m^3P	0.006	0.27	0.024	109
	Ammonia nitrogen	g/m^3N	<0.003	0.37	0.020	109
	Nitrite	g/m^3N	<0.001	0.021	0.007	99
	Nitrate	g/m^3N	0.006	0.99	0.34	101
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.20	0.26	106
	Total nitrogen	g/m^3N	0.15	1.65	0.62	105
	pH		6.8	8.6	7.5	101
L2 Hypolimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.029	0.008	108
	Total phosphorus	g/m^3P	0.008	0.46	0.022	109
	Ammonia nitrogen	g/m^3N	<0.003	0.44	0.071	109
	Nitrite	g/m^3N	<0.001	0.022	0.008	99
	Nitrate	g/m^3N	0.02	0.92	0.51	103
	Total Kjeldahl nitrogen	g/m^3N	<0.01	0.99	0.27	108
	Total nitrogen	g/m^3N	0.45	1.72	0.78	108
	pH		6.5	7.4	6.9	102
L3 Epilimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.023	0.004	104
	Total phosphorus	g/m^3P	0.004	0.33	0.019	109
	Ammonia nitrogen	g/m^3N	<0.003	0.183	0.011	109
	Nitrite	g/m^3N	<0.001	0.020	0.005	99
	Nitrate	g/m^3N	<0.01	0.83	0.35	101
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.15	0.25	105
	Total nitrogen	g/m^3N	0.18	1.51	0.61	105
	pH		6.6	8.7	7.6	101
L3 Hypolimnion	Dissolved reactive phosphorus	g/m^3P	<0.003	0.026	0.006	109
	Total phosphorus	g/m^3P	0.005	0.67	0.017	109
	Ammonia nitrogen	g/m^3N	<0.003	0.34	0.005	109
	Nitrite	g/m^3N	<0.001	0.020	0.001	99
	Nitrate	g/m^3N	0.05	1.00	0.58	103
	Total Kjeldahl nitrogen	g/m^3N	<0.01	1.63	0.16	108
	Total nitrogen	g/m^3N	0.30	2.2	0.73	108
	pH		6.5	7.2	6.8	103

Table 13 Nutrient water quality monitoring data for Lake Rotorangi site L2: Epilimnion (2018-2019)

Parameter		Date			
	Unit	24 Oct 2019	20 Feb 2019	19 Mar 2019	19 Jun 2019
Sample depth	m	1.8	4.5	7.5	5.5
Dissolved reactive phosphorus	g/m³P	0.002	0.001	0.002	0.006
Total phosphorus	g/m³P	0.040	0.029	0.020	0.024
Ammonia-N	g/m³N	0.007	<0.005	0.067	0.022
Nitrite	g/m³N	0.005	0.003	0.006	0.009
Nitrate	g/m³N	0.37	0.025	0.112	0.62
TKN	g/m³N	0.26	0.26	0.29	0.17
Total nitrogen	g/m³N	0.63	0.29	0.41	0.80
pH	pH	7.8	8.0	7.3	7.2

Table 14 Nutrient water quality monitoring data for Lake Rotorangi site L2: Hypolimnion (2018-2019)

Parameter		Date			
	Unit	24 Oct 2019	20 Feb 2019	19 Mar 2019	19 Jun 2019
Sample depth	m	17	25	25	32
Dissolved reactive phosphorus	g/m³P	0.006	0.004	0.004	0.003
Total phosphorus	g/m³P	0.022	0.016	0.015	0.014
Ammonia-N	g/m³N	<0.005	0.073	0.0067	0.20
Nitrite	g/m³N	0.002	0.003	0.001	0.002
Nitrate	g/m³N	0.66	0.49	0.48	0.22
TKN	g/m³N	0.19	0.26	0.20	0.31
Total nitrogen	g/m³N	0.86	0.75	0.68	0.53
pH	pH	7.1	6.9	7.0	7.0

Table 15 Nutrient water quality monitoring data for Lake Rotorangi site L3: Epilimnion (2018-2019)

Parameter		Date			
	Unit	24 Oct 2019	20 Feb 2019	19 Mar 2019	19 Jun 2019
Sample depth	m	1.8	4.5	5.4	7.2
Dissolved reactive phosphorus	g/m³P	<0.001	0.002	0.001	0.005
Total phosphorus	g/m³P	0.022	0.009	0.011	0.018
Ammonia-N	g/m³N	0.006	0.007	0.018	<0.005

Parameter		Date			
	Unit	24 Oct 2019	20 Feb 2019	19 Mar 2019	19 Jun 2019
Nitrite	g/m^3N	0.005	0.003	0.002	0.009
Nitrate	g/m^3N	0.48	0.069	0.104	0.60
TKN	g/m^3N	0.27	0.27	0.22	0.14
Total nitrogen	g/m^3N	0.75	0.34	0.33	0.74
pH	pH	7.9	7.8	7.4	7.3

Table 16 Nutrient water quality monitoring data for Lake Rotorangi site L3: Hypolimnion (2018-2019)

Parameter		Date			
	Unit	24 Oct 2019	20 Feb 2019	19 Mar 2019	19 Jun 2019
Sample depth	m	30	32	33	32
Dissolved reactive phosphorus	g/m^3P	0.005	0.003	0.002	0.002
Total phosphorus	g/m^3P	0.018	0.010	0.009	0.008
Ammonia-N	g/m^3N	<0.005	<0.005	<0.005	<0.005
Nitrite	g/m^3N	<0.001	<0.001	<0.001	<0.001
Nitrate	g/m^3N	0.66	0.60	0.62	0.55
TKN	g/m^3N	0.15	0.13	0.13	0.14
Total nitrogen	g/m^3N	0.80	0.73	0.75	0.70
pH	pH	7.0	6.9	6.9	7.0

3.1.4.2 Epilimnion

The nutrient concentrations of the epilimnetic waters of the main lake were again characterised by relatively low levels of available plant nutrients (Table 13 and Table 15) on the majority of the monitoring occasions. In general, the lowest concentrations of nutrients, such as TN and TP, were coincident with times when the lake waters were strongly stratified (e.g. summer and autumn). Concentrations of all nutrients were within previously recorded ranges. Total phosphorus concentrations have varied in the past in association with temporal and spatial fluctuations in suspended solids concentrations. These variations were not apparent in the period under review, where suspended solids remained low throughout that lake.

In most previous monitoring years, there was a significant reduction in the readily available nutrient species (particularly nitrate-N) with lake stratification in late summer and autumn at sites L2 and L3, attributable to a possible increase in biological activity e.g. uptake by phytoplankton. During the period under review, ammonia-N and nitrate-N did not follow this pattern, with concentrations being the highest in autumn. Consistent with this, pH levels were slightly elevated in spring and late summer (7.8 to 8.0), but decreased in autumn. Elevated pH levels would often occur in conjunction with a small increase in dissolved oxygen, due to increased phytoplankton photosynthetic activity.

One possible explanation for this atypical result is a river fresh which occurred just prior to the March 2019 sampling. This may have caused the pH to be lowered while simultaneously increasing the concentrations of certain nutrients. Chlorophyll-a concentrations indicated that this fresh did not cause a significant change in phytoplankton productivity. This is consistent with dissolved oxygen concentrations (Table 7), which were highest in autumn (111 to 112% at both sites). This supersaturation indicates that phytoplankton photosynthetic activity was not significantly affected by this fresh.

3.1.4.3 Hypolimnion

The onset of anoxic conditions in the hypolimnetic waters at site L2 during stratification resulted in increased ammonia-N levels between February and June 2019 (Table 14). At site L3, complete anoxia in the hypolimnion was not recorded and ammonia-N levels remained low during the period under review (Table 16). The pH level in the hypolimion was consistently close to neutral (6.9 to 7.1 pH units) and was often significantly lower (by up to 1.1 pH units) than the pH of the epilimnion. These differences in pH are typical particularly during periods of stratification. As is typical, pH levels in the epilmnion and hypolimnion were more similar in winter when the lake was mixed.

The lengthy period of partial to complete stratification at sites L2 and L3 contributed to the variability in nutrient concentrations. The total phosphorus levels at sites L2 and L3 showed some variability in relation to changes in turbidity, particularly at site L2 in spring 2018, caused by suspended sediment settling through the hypolimnetic waters.

3.1.4.4 Bottom of hypolimnion

In an addendum to the Burns (1995) report it was noted that dissolved oxygen concentrations close to the lake bottom were often near zero in February and March each year. Burns recommended that on these occasions additional samples should be collected from near the lake bottom (at sites L2 and L3) in order to determine whether this anoxia had caused the redox potential at the sediment-water interface to drop to a point whereby dissolved reactive phosphorus and/or ammonia had been released from the sediment.

Samples for this purpose have been collected at sites L2 and L3 in February and March of each monitoring year since 1996 during anoxic conditions at site L2 and usually approaching anoxia at site L3. A summary of historical data is provided in Table 17.

Table 17 Statistical summary of nutrients and related data during late summer-autumn in the lower hypolimnion in relation to comparative hypolimnetic data at sites L2 and L3 from 1996 to June 2018

Site	Location			Lower hypolimnion (near bed)			Hypolimnion			
	Parameter	Unit	N	Minimum	Maximum	Median	N	Minimum	Maximum	Median
L2	Dissolved reactive phosphorus	g/m^3P	44	<0.003	0.040	0.007	44	<0.003	0.017	0.008
	Total phosphorus	g/m^3P	44	0.012	0.28	0.023	44	0.008	0.220	0.020
	Ammonia nitrogen	g/m^3N	44	0.015	0.62	0.143	44	<0.003	0.297	0.106
	Nitrate + nitrite	g/m^3N	39	<0.01	0.75	0.43	41	0.02	0.72	0.47
	Temperature	°C	44	8.1	14.3	9.5	44	8.1	14.4	9.7
	Turbidity	NTU	44	2.4	310	9.0	44	1.6	230	3.7
	Dissolved oxygen	g/m^3	44	0.0	6.4	0.1	44	0.0	7.6	0.1
	pH		35	6.5	7.0	6.7	44	6.5	7.3	6.8
L3	Dissolved reactive phosphorus	g/m^3P	43	<0.003	0.032	0.007	43	<0.003	0.024	0.006
	Total phosphorus	g/m^3P	43	0.008	0.298	0.020	43	0.006	0.082	0.017
	Ammonia nitrogen	g/m^3N	43	<0.003	0.111	0.006	43	<0.003	0.064	0.005
	Nitrate + nitrite	g/m^3N	39	0.12	0.77	0.58	43	0.17	0.78	0.61
	Temperature	°C	43	7.4	14.7	9.2	43	7.7	15.6	9.3
	Turbidity	NTU	42	0.7	140	6.2	43	0.7	65	1.8
	Dissolved oxygen	g/m^3	43	0.0	3.5	0.7	43	0.0	4.8	1.7
	pH		33	6.6	7.0	6.7	43	6.6	7.1	6.8

Historical median data (1996-2018) indicate that the general trend at both sites (L2 and L3) has been a small increase in ammoniacal nitrogen and very small decrease in nitrate N in the hypolimnetic anoxic zone near the sediment interface compared to the hypolimnetic water column. There has been no significant change in phosphorus species at site L2 but some increase at site L3, for total phosphorus, noting that a more marked increase in turbidity has been typical at this site nearer the sediment interface.

The nutrient analytical results from sampling in February and March 2019, are summarised in Table 18 and may be compared with results of samples collected from higher up the water column within the hypolimnion on the same occasion (Table 14 and Table 16).

Table 18 Nutrient water quality monitoring data for Lake Rotorangi sites L2 and L3: lower hypolimnion (above the lake bed) in the 2018-2019 period

Site		L2		L3	
Parameter	Unit	20 Feb 2019	19 Mar 2019	20 Feb 2019	19 Mar 2019
Sample depth	m	36	39	50	50
Dissolved reactive phosphorus	g/m^3P	0.004	0.004	0.004	0.004
Total phosphorus	g/m^3P	0.024	0.029	0.013	0.010
Ammonia-N	g/m^3N	0.22	0.25	<0.005	<0.005
Nitrate + nitrite-N	g/m^3N	0.36	0.26	0.57	0.53
[Dissolved oxygen]	g/m^3	[0]	[0]	[0.5]	[0]
[Turbidity]	NTU	[15.3]	[16.8]	[2.6]	[2.6]
[pH]		[7.0]	[6.9]	[6.9]	[7.0]
[Total BOD_5]	g/m^3	-	-	-	-

[ ] = additional parameters N/S = not able to sample

During the summer stratification period anoxic conditions were present in the lower hypolimnion at site L2 but not at site L3 (see Figure 3). Both sites showed no significant increases in dissolved reactive phosphorus in the lower hypolimnetic waters near the sediment interface (Table 18) compared with higher in the water column of the hypolimnion (Table 14 and Table 16), but an increase in total phosphorus was observed at site L2 in February and March 2019 when there was an increase in turbidity. Increases in ammonia nitrogen (0.22 and 0.25 g/m^3N) at site L2 were coincident with reducing conditions deep in the anoxic zone on both survey occasions but there were no increases in ammonia nitrogen at site L3.

Differences in nutrient species between the deeper hypolimnetic waters and waters higher in the hypolimnion were slightly more marked at site L2 during late summer and autumn when more widespread anoxia was recorded. However all nutrient concentrations measured near the lake bed at sites L2 and L3 (Table 18) were within the ranges of historical data (Table 17) measured during summer-autumn anoxic and near anoxic conditions. Ammonia-N was present above median values under anoxic conditions at site L2.

Burns (2006) concluded that DRP and ammonia-N levels indicated a relative lack of nutrient release under anoxic conditions, consistent with lakebed sediment not yet contaminated with high nutrient levels.

Monitoring of the waters of the lower hypolimnion at sites L2 and L3 will be continued during February and March surveys as a component of the long-term monitoring programme.

3.1.4.5 General

Nutrient data surveyed during the period under review were within ranges recorded since 1990 for all sites.

Nutrient data gathered over the 1990 to 2006 period have been analysed by a consultant (Burns, 2006) and by TRC for the 1990-2018 period (Appendix II), and indicate for the lacustrine (lake-like) sites L2 and L3, that total nitrogen (TKN plus nitrate) availability is surplus to phytoplankton requirements and that phosphorus is the growth-limiting nutrient. Phosphorus is reduced more than nitrogen by phytoplankton uptake and sedimentation while nitrates in the lake remain high. While TP and TN nutrients have shown non-significant temporal increases over the twenty-seven year period, a more significant temporal increase in nitrate-N is consistent with a very slow rate of increase in trophic level (Burns, 2006 and Appendix II).

3.1.4.6 Bacteriological surface water quality

The Council undertakes an extensive freshwater contact recreational bacteriological state of the environment monitoring programme at various bathing sites over summer months (see TRC, 2019). In recognition of the recreational uses of Lake Rotorangi (mainly boating and water-skiing at site L2, but also at site L3), bacteriological surface water quality sampling are undertaken at both sites on each survey occasion. These results are presented in Table 19 and Table 20.

Table 19 Bacteriological quality monitoring data for Lake Rotorangi site L2: surface water (2018-2019)

Site		Date			
Parameter	**Unit**	**24 Oct 2019**	**20 Feb 2019**	**19 Mar 2019**	**19 Jun 2019**
Time	NZST	0913	0930	0906	1012
Temperature	˚C	17.7	23.1	22.2	11.3
Turbidity	NTU	1.05	1.52	0.69	2.8
E.coli	/100 mL	2	3	10	23

Table 20 Bacteriological water quality monitoring data for Lake Rotorangi site L3: Surface (2018-2019)

Site		Date			
Parameter	**Unit**	**24 Oct 2019**	**20 Feb 2019**	**19 Mar 2019**	**19 Jun 2019**
Time	NZST	1103	1215	1103	1201
Temperature	˚C	17.4	24.3	22.5	11.9
Turbidity	NTU	1.00	0.54	0.66	1.43
E.coli	/100 mL	3	<1	2	3

Bacteriological water quality was well within the guidelines for contact recreation (MfE, 2003) at both sites on all sampling occasions. Sparse birdlife has been noted on the water in the vicinity of sites L2 and L3 in previous surveys and, although minimal recreational usage was recorded on sampling occasions, boating and water-skiing are popular activities at site L2 in particular and swimming also occurs at site L3.

3.2 Biological monitoring

3.2.1 Methods

During the 2018-2019 monitoring periods the biological monitoring of Lake Rotorangi involving the Regional Council included monitoring of the lake phytoplankton communities

Phytoplankton (open-water algae) sub-samples were taken from the chlorophyll-a samples collected from the photic zone at each of the two lake sites in October 2018, and February, March and June 2019. The phytoplankton samples were preserved with Lugol's iodine solution and all samples were later identified under a compound microscope using up to 400 x magnification.

The macrophyte survey is next due in April 2021, and was performed last in April 2018, when both banks were visually surveyed from a boat. The dominant species was recorded, with the presence of other species noted and mapped.

Benthic macroinvertebrate samples were collected by Ekman dredge from the lakebed at sites L2 and L3 in conjunction with the survey of October 2017, as a long-term component of the monitoring programme. These samples were run through a 0.5 mm sieve, before being sorted and identified under a stereoscopic microscope. This is next due in October 2020.

3.2.2 Results

3.2.2.1 Lake phytoplankton communities

Phytoplankton samples were collected from Lake Rotorangi on 24 October 2018, and 20 February, 19 March and 19 June 2019. These samples were taken from within the photic zone (surface waters) of sites L2 and L3. Table 21 and Table 22 list the phytoplankton taxa found at each site. Taxa data from previous years are listed in previous Annual Reports, but particularly in TRC, 2009.

3.2.2.1.1 Site L2

Site L2 in the central reaches of the lake has generally supported more lake-like algal communities than previously found at site L1 (see TRC, 2009).

Table 21 Phytoplankton found at site L2 in Lake Rotorangi during the 2018-2019 period

Date	24 Oct 2018	20 Feb 2019	19 Mar 2019	19 Jun 2019
GREEN ALGAE				
Unidentified (unicellular)		P		P
Unidentified colonies		P	P	P
Closterium				P
Cosmarium			P	P
Chlorella		P		
Oocystis		P		
Staurastrum		P	P	P
Kirchneriella				P
Dictyosphaerium		P		
Micractinium				P
Golenkinia		P		
Scenedesmus				P
Mougeotia		P		
CYANOBACTERIA				
Dolichospermum[1]			P	P
DIATOMS				
Synedra		A		
Navicula		P		
Fragilaria		P		P
GOLDEN BROWNS				
Mallomonas		P	P	P
Dinobryon		A		P
DINOFLAGELLATES				
Peridinium			P	
EUGLENOIDS				
Trachelomonas	P	P	P	P
CRYPTOPHYTES				
Cryptomonas		A	P	P
TOTAL	1	15	8	14

P – Present

A – Abundant

1 – formerly *Anabaena*

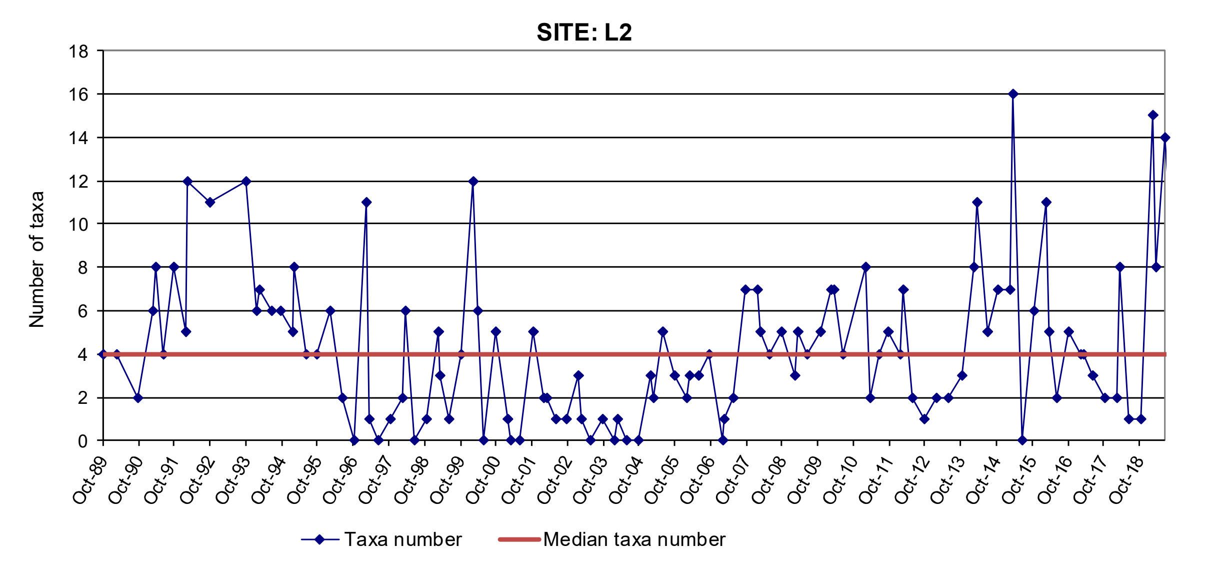

Figure 5 Number of phytoplankton taxa recorded at site L2 in Lake Rotorangi since monitoring began in 1989

Moderate to high numbers of taxa (1 to 15) were recorded at site L2 during the period under review. With the exception of the spring 2018 sample, taxa richness was substantially higher than the median richness of 4 taxa. Chlorophyll-a concentrations ranged from 1.1-3.7 mg/m^3 (Table 11), congruent with taxa being recorded as abundant on only one sampling occasion. The three taxa recorded as abundant were the diatom *Synedra,* the cryophyte *Cryptomonas* and the golden brown alga *Dinobryon*.

A total of 22 taxa were recorded at this site throughout the year, and one taxon (the euglinoid *Trachelomonas*) was present on all four sampling occasions, while four taxa were present on three of the four sampling occasions (*Cryptomonas*, the golden brown alga *Mallomonas*, the green alga *Staurastrum* and unidentified colonial green algae).

3.2.2.1.2 Site L3

Moderate to high taxa richness was found at L3 during the period under review. As was the case at site L2, taxa richness was substantially higher than the median richness of 4 taxa except in spring 2018. Chlorophyll-a concentrations ranged from 0.9- 3.0 mg/m^3 (Table 11).

Table 22 Phytoplankton found at site L3 in Lake Rotorangi during the 2018-2019 period

Date	24 Oct 2018	20 Feb 2019	19 Mar 2019	19 Jun 2019
GREEN ALGAE				
Unidentified (unicellular)	P			P
Unidentified colonies		P	P	P
Cosmarium		P	P	P
Chlorella		P	P	
Oocystis		P	P	
Staurastrum		P	P	P
Coelastrum		P	P	
Micractinium			A	P
Eudorina				P
Elakatothrix		P	P	
CYANOBACTERIA				
Dolichospermum[1]				P
DIATOMS				
Asterionella		A		
Synedra		P	P	
Aulacoseria		P		
Fragilaria		P	A	P
GOLDEN BROWNS				
Mallomonas		P	P	P
Dinobryon		P	P	
DINOFLAGELLATES				
Peridinium			P	
EUGLENOIDS				
Trachelomonas	P	P	P	
CRYPTOPHYTES				
Cryptomonas		A	A	P
TOTAL	2	15	15	10

P – Present

A – Abundant

1 – Formerly *Anabaena*

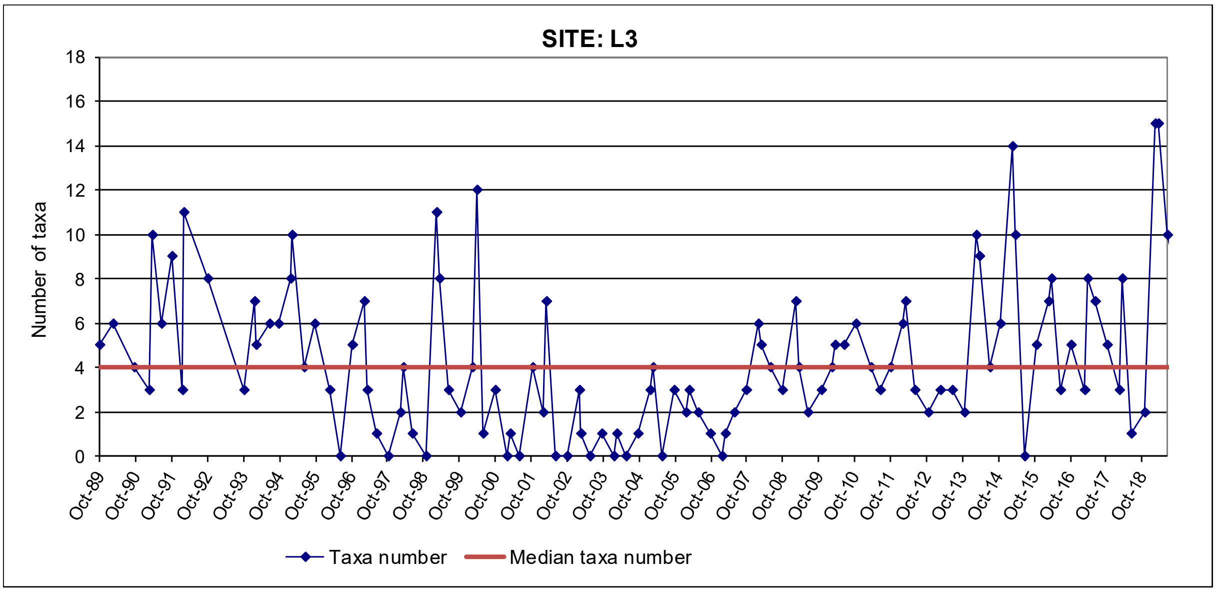

Figure 6 Number of phytoplankton taxa recorded at site L3 in Lake Rotorangi since monitoring began in 1989

A total of 20 taxa were recorded during the period under review, with up to 15 taxa present on any one sampling occasion. Abundant taxa were recorded on two occasions, with the cryophyte *Cryptomonas* being abundant in both late summer and autumn. The diatom *Asterionella* was also abundant in late summer, while the diatom *Fragilaria* and the green alga *Microactinium* were abundant in autumn. Seven taxa were present on three of the four sampling occasions during the year.

3.2.2.1.3 General comments

Phytoplankton density limiting factors include:

- limited nutrient levels in the lake;
- the settling of algal cells within the dark hypolimnetic waters;
- flood events reducing the clarity of surface waters and flushing surface waters along the length of the lake;
- the limited and variable retention time of water in the lake;
- grazing of phytoplankton by zooplankton (primarily microscopic crustacea); and
- cooler winter temperatures.

The absence of significant blooms of algae to date has indicated that one or more of these limiting factors have prevented algal population increases from continuing for long periods of time. Phytoplankton survey results to date indicate that the open-water algal community composition of Lake Rotorangi is determined by the ability of opportunist taxa to proliferate during the very limited periods of favourable conditions (e.g. late summer/autumn). Phytoplankton provides the food source for the microscopic crustacea in the open water (the major component of zooplankton). Such zooplankton taxa as cladocerans *Daphnia* and *Ceriodaphnia* have been recorded in highly variable densities in Lake Rotorangi in past years. Large numbers of these cladocerans have been recorded in the stomachs of perch (*Perca fluviatilis*) taken from Lake Rotorangi. Some of the algal taxa recorded in the lake phytoplankton are likely to have drifted downstream from the discharge from the Stratford oxidation pond system (where extensive algal populations are a feature of the biological treatment system), and from the mid-reaches of the Patea River. [Note: A major upgrade to the Stratford wastewater treatment plant in 2009 has been designed to reduce the algal population component of the effluent discharge to the river downstream of Stratford (TRC, 2018a)].

In summary, taxa richness was much higher than usual in Lake Rotorangi from late summer to winter 2019, with both sites recording up to 11 taxa more than the running median for the respective sites. Despite this higher than usual diversity, chlorophyll-a concentrations were within a relatively low range. This indicates that although there was increased diversity, there were not particularly high abundances of the taxa present. There were also some differences in the phytoplankton communities between sites L2 and L3, with 12 of a total 27 taxa recorded in the lake during the year present at only one site.

3.2.2.2 Benthic macroinvertebrate fauna

A review of the monitoring undertaken by Council staff in late 1991 in conjunction with Dr V M Stout (Department of Zoology, University of Canterbury), indicated that an important additional parameter (benthic macroinvertebrate presence/absence information) should be included as a long term lake status indicator. Sampling from the lake bed (at the deeper sites L2 and L3) was recommended once annually in late winter/spring prior to lake stratification (and the chironomid hatching period).

Generally, the limited information gathered on the macro-benthos of New Zealand lakes indicates that lakes are rather poor in terms of numbers of species, with the main groups found including annelid worms, chironomid midges, ceratopogonid flies and molluscans (Forsyth, 1975 and 1977).

The initial sampling of the lake bed at the deeper sites (L2 and L3) was undertaken in October 1992 with samples collected at similar times over subsequent years until the October 2013 survey using an Ekman dredge. Following the October 2013 survey, the frequency of monitoring was reduced to triennial sampling. The October 2017 survey was the first survey at the reduced frequency. Macroinvertebrate sampling was not undertaken during the period under review and will next be undertaken in October 2020.

The results of the October 2017 survey are reported in the 2016-2018 Lake Rotorangi water quality and biological monitoring report (TRC 2018).

In general, the paucity and lack of diversity of the fauna continues to be indicative of low dissolved oxygen levels, consistent with the often lengthy periods of anoxic conditions during lake stratification common to these deeper sites.

3.2.2.3 Aquatic macrophyte survey

The latest survey of the aquatic macrophytes in Lake Rotorangi was performed on 15 April 2018. Surveys are now undertaken as a requirement of consent 0489-2, which requires that surveys be undertaken every three years (commencing in 2012). This survey was not undertaken during the period under review and will next be undertaken in autumn 2021.

The results of the April 2018 macrophyte survey are reported in the 2016-2018 Lake Rotorangi water quality and biological monitoring report (TRC 2018).

4 Conclusions

4.1 Discussion of 2018-2019 programme

4.1.1 Water quality

Pre-stratification, two summer stratification, and post-stratification (winter) sampling surveys were performed during each monitoring period at times dictated by requirements for trend detection purposes.

The annual cycle of stratification was recorded in the mid and lower lake during the summer-autumn period in 2018-2019 with anoxic hypolimnetic water recorded at site L2 and oxygen depleted hypolimnetic water recorded at site L3. Normal lake overturn was complete at site L2 but only partially complete at site L3 in mid-winter. These conditions generally were similar to those recorded during the majority of the previous monitoring years and are a particular feature of the lower lake site. Complete re-oxygenation of the water column due to further mixing at site L3 might have been anticipated later in winter (as had been the situation recorded in August 2008 and found in July 2012 and July 2013 from readings taken through the water column at the log boom as a part of the Patea Hydro Electric Power Scheme - aquatic monitoring plan), although spring 2013 records at site L3 suggest that mixing may never be complete nearer the lake bed.

Primary productivity measurements (chlorophyll-a) continued to indicate that predicted eutrophic lake conditions have not eventuated. The lake biologically continues to exhibit mesotrophic bordering on eutrophic conditions as confirmed by a NIWA consultant's report (Burns, 1995) commissioned during the 1995-1996 period and subsequent follow-up reports (Burns, 1999; Burns et al, 2000 and Burns, 2006) and the most recent trend evaluation for the period 1990 to 2018 (Appendix II) which was carried out by the Council. However, relatively high turbidity levels (caused by riverine derived fine silt) from time to time have increased total phosphorus and nitrogen levels and lowered secchi disc values, indicative of a trend toward slightly eutrophic conditions (Burns, 2006). Nutrient supply has been limited principally to those quantities present in the river inflow waters. Despite low dissolved oxygen concentrations and periods of anoxic conditions in the lower waters of the hypolimnion, minimal increases in nutrient concentrations in these waters (usually due to the increased solubility of nutrients from sediments and decomposing vegetation under reducing conditions), have been recorded, with the main variations relating to relatively small increases in ammonia levels measured during this period with minor changes in total phosphorus levels (usually coincident with increased turbidity due to fine sediment).

Variability in levels of turbidity and suspended solids concentrations at the times of the four survey in 2018-2019 were related to the temporal proximity to river freshes. Secchi disc transparencies and turbidity were generally similar or respectively higher and lower than historical median values, indicating that the freshes prior to sampling were of relatively small magnitude. As has been noted in the past, lake surface water suspended solids concentrations generally were not excessive at mid and lower lake sites and were due to the finer colloidal material which remained suspended and would be expected to be carried through the lake.

The calculation of VHOD has a number of shortfalls and inaccuracies in the calculation method. Further, the nature of Lake Rotorangi and the variability in the VHOD rates means that the value of this parameter is of questionable value for trend detection purposes. The limitations of this parameter are discussed more fully in Section 3.1.2. Increased sampling effort would be required to improve the annual VHOD calculation, but would not address many of the shortcomings of this parameter. It is therefore recommended that the calculation of VHOD is removed as a component of the Lake Rotorangi physicochemical and biological water quality monitoring programme. It should be noted that the temperature and dissolved oxygen profiles of the lake will continue to be collected. This will allow VHOD rates to be calculated in future should inadequacies with the calculation methodology be addressed.

The most recent lake water quality trend analysis, performed by the Council for the 28 year period 1990-2018 (see Appendix II) has continued to support the findings and conclusions of Burns, 2006. i.e. that the trophic level continues to increase at a very small, insignificant annual rate of change (currently 0.02 $\pm$ 0.01 TLI units per year). However, given the tendency for the reservoir water to contain elevated (fine) silt levels, which artificially elevate the trophic index, the trophic category is more appropriately mesotrophic. This is further confirmed by mesotrophic chlorophyll-a level. The analysis also notes significant increase in the average concentration of chlorophyll-a and total phosphorus, but not the other key variables (secchi disc visibility and total nitrogen). The other variable showing a significant temporal trend was nitrate, which is increasing.

4.1.2 Biology

No phytoplankton blooms were recorded in Lake Rotorangi. The lake has been unable to sustain significant abundances of planktonic algae for long due to the frequency of river freshes. Low to moderate numbers of algal taxa were recorded, partly as a result of the frequency of river freshes through the system. Several of the taxa that have been found to date probably originated from the Stratford oxidation pond wastewater treatment system discharge (where extensive algal populations have been a feature of the biological treatment system) and from the mid reaches of the Patea River. Phytoplankton results to date indicate that lake phytoplankton community composition is determined by opportunistic taxa which have the ability to proliferate during favourable conditions which may be confined to very limited periods often due to the frequency of river freshes moving down the lake. Chlorophyll-a concentrations in the lake were low to moderate at survey times although phytoplankton communities were more diverse than is typical in Lake Rotorangi. This indicates that although diversity was higher than usual, abundances were relatively low.

The macrophyte survey was conducted in 2017-2018 at a time of high turbidity throughout the length of the lake, caused by a recent fresh in the upper catchments, which may have affected the discovery of submerged plants. The oxygen weed *Egeria densa* was identified as the dominant macrophyte in the lower part of the lake, and *Ceratophyllum demersum* (hornwort) in parts of the mid-section. No other species was recorded as dominant, and only one other species, *Glossostigma elatinoides*, was found. *Lagarosiphon major*, which had been recorded in all previous surveys was not found, possibly as a result of the high turbidity. This is the third record of hornwort in Lake Rotorangi. In addition to those species recorded by the Council, an additional three new species were recorded by NIWA in April 2012 when commissioned by TrustPower to assess the hornwort community within the lake. It is unlikely that these other species will ever become abundant. Hornwort on the other hand is considered highly invasive, and is expected to eventually become dominant, out-competing *E. densa* and *L. major,* although this had not occurred at the time of the October 2018 survey. While this is not expected to cause significant impacts on the ecology of Lake Rotorangi or on the hydroelectric scheme, there is now greater potential for it to spread to nearby lakes, where such impacts could be much more severe e.g. Lake Rotokare. The next survey is due to be performed in the 2020-2021 period.

Appropriate warning signs about aquatic weeds, positioned at the three principal boat ramps along the lake's length, publicise the problems that could result from the introduction of further nuisance aquatic plants by recreational users, and their responsibilities for preventing the transportation of aquatic plants between the waterways. These were updated during the 2015-2016 period, with particular reference to hornwort.

A very sparse macroinvertebrate fauna, but with an absence of oligochaete (tubificids) worms, has been recorded from the fine sediments of the lake bed between 1996-2017 at the mid lake site and at the lower lake site consistent with periodic occurrences of anoxic or oxygen depleted conditions recorded at these two relatively deep sites. This component of the programme is next due in the 2020-2021 monitoring period.

4.2 2016-2018 Report's recommendations

The recommendation contained in the 2016-2018 Annual Reports based upon the monitoring programme results was:

1. THAT the Lake Rotorangi physicochemical and biological water quality monitoring programme continue on an annual basis as a component of the Council's State of the Environment monitoring programme, with every third year of the programme also undertaken in conjunction with the Patea Hydro Electric Power Scheme - aquatic monitoring plan (next in 2020-2021), and that the requisite macrophyte and benthic macroinvertebrate surveys be components of the 2020-2021 programme.

This recommendation (1) was implemented with the continuation of a State of the Environment monitoring programme to include the physicochemical and biological water quality monitoring including the triennial performance of the macrophyte survey. Once every three years this will be undertaken at TrustPower's expense, as required by consent 0489, and this is included in the Patea Hydro Electric Power Scheme - aquatic monitoring plan.

4.3 Alterations to monitoring programme for 2019-2020

In the case of the State of the Environment monitoring programme for Lake Rotorangi, it is considered that the current monitoring is generally appropriate, with every third year of the programme to be performed in conjunction with the Patea Hydro Electric Power Scheme - aquatic monitoring plan, which is next to be conducted in the 2020-2021 period. The exception to this is the VHOD calculation as discussed in Sections 3.1.2 and 4.1.1.

No alterations are required to the 2019-2020 programme, although the data will no longer be used to calculate VHOD given the shortcomings of this parameter. It is noted that the designated macrophyte survey will next be undertaken in early 2021 and the benthic macroinvertebrate survey in spring 2020.

Recommendations to this effect are attached to this report.

5 Recommendations

The following recommendations are based on the results of the 2018-2019 water quality and biological monitoring programmes and the contractual requirements of the resource consents held by Trustpower for the Patea Hydro Electric Power Scheme on Lake Rotorangi:

1. THAT the Lake Rotorangi physicochemical and biological water quality monitoring programme continue on an annual basis as a component of the Council's State of the Environment monitoring programme, with every third year of the programme also undertaken in conjunction with the Patea Hydro Electric Power Scheme - aquatic monitoring plan (next in 2020-2021), and that the requisite macrophyte and benthic macroinvertebrate surveys be components of the 2020-2021 programme.
2. THAT the calculation of VHOD rates as a component of the Lake Rotorangi physicochemical and biological water quality monitoring programme be discontinued due to the inaccuracies and shortfalls of the calculation method.

6 Acknowledgements

The programme Job Manager was Sheree Tidswell (Environmental Scientist). The principal author of the Annual Report was Katie Blakemore (Technical Officer), who provided the statistical trend analyses. Field lake sampling were performed by Sheree Tidswell assisted by boatperson Regan Diggelmann. Hydrological data was provided by Fiona Jansma (Data Analyst). All water quality analytical work was performed by Hill Laboratories. Phytoplankton analyses were performed by Darin Sutherland and Brooke Thomas (Environmental Scientists) in the Council's biology laboratory.

Glossary of common terms and abbreviations

The following abbreviations and terms are used within this report:

anoxia	absence of dissolved oxygen
aquatic macrophyte	water plants
benthic	bottom living
black/secchi disc	measurement of visual clarity (metres) through the water (horizontally/vertically)
biomonitoring	assessing the health of the environment using aquatic organisms
chlorophyll-a	productivity using measurement of phytoplankton pigment (mg/m^3)
cumec	volumetric measure of flow (cubic metre per second)
conductivity	Conductivity, an indication of the level of dissolved salts in a sample, usually measured at 25°C and expressed in µS/cm
DO	dissolved oxygen measured as g/m^3 (or saturation (%))
DRP	dissolved reactive phosphorus
E.coli	*Escherichia coli*, an indicator of the possible presence of faecal material and pathological micro-organisms. Expressed as the number of organisms per 100ml
epilimnion	lake zone above the thermocline (mixed surface layer)
faecal coliforms	an indicator of the possible presence of faecal material and pathological micro-organisms. Expressed as the number of organisms per 100ml
fresh	elevated flow in a stream, such as after heavy rainfall
g/m^3	grammes per cubic metre, and equivalent to milligrammes per litre (mg/L). In water, this is also equivalent to parts per million (ppm), but the same does not apply to gaseous mixtures
hypolimnion	zone below the thermocline in a stratified lake
l/s	litres per second
mesotrophic	intermediate condition of nutrient enrichment between oligotrophic and eutrophic in lakes
mS/m	millisiemens per metre
µS/cm	Microsiemens per centimetre.
NH_4	ammonium, normally expressed in terms of the mass of nitrogen (N)
NO_3	nitrate, normally expressed in terms of the mass of nitrogen (N)
NTU	Nephelometric Turbidity Unit, a measure of the turbidity of water
overturn	remixing of a lake after stratification
pH	a numerical system for measuring acidity in solutions, with 7 as neutral. Numbers lower than 7 are increasingly acidic and higher than 7 are increasingly alkaline. The scale is logarithmic i.e. a change of 1 represents a ten-fold change in strength. For example, a pH of 4 is ten times more acidic than a pH of 5
photic zone	upper section of lake penetrated by light

physicochemical	measurement of both physical properties(e.g. temperature, clarity, density) and chemical determinants (e.g. metals and nutrients) to characterise the state of an environment
plankton	plants and animals freely moving in open water
resource consent	refer Section 87 of the RMA. Resource consents include land use consents (refer Sections 9 and 13 of the RMA), coastal permits (Sections 12, 14 and 15), water permits (Section 14) and discharge permits (Section 15)
RMA	Resource Management Act 1991 and subsequent amendments
SS	suspended solids
stratification	formation of thermal layers in lakes
temp	temperature, measured in ˚C (degrees Celsius)
thermocline	zone of most rapid temperature change in stratified lakes
trophic level	amount of nutrient enrichment of a lake
turb	turbidity, expressed in NTU
UI	Unauthorised Incident
UIR	Unauthorised Incident Register – contains a list of events recorded by the Council on the basis that they may have the potential or actual environmental consequences that may represent a breach of a consent or provision in a Regional Plan
VHOD	Volumetric hypolimnetic oxygen depletion. The note of dissolved oxygen decrease in the lower layer of the lake under stratified conditions. A measure of lake productivity
water column	water overlying the lake bed

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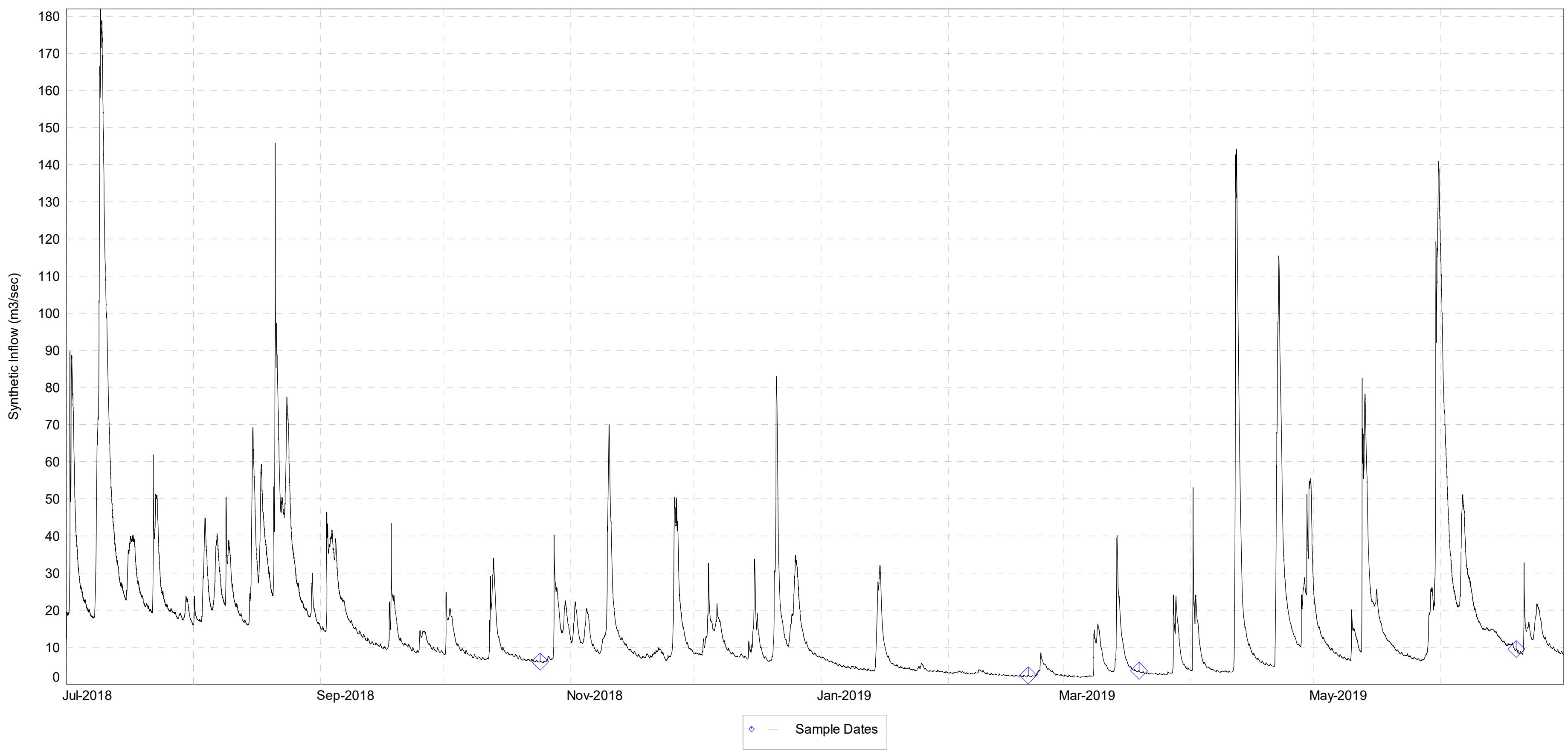
Appendix I

Flow data for the Patea River at Skinner Road, the Mangaehu River at Raupuha Road bridge, and the synthesised inflow into Lake Rotorangi for the period 1 July 2016 to 30 June 2018

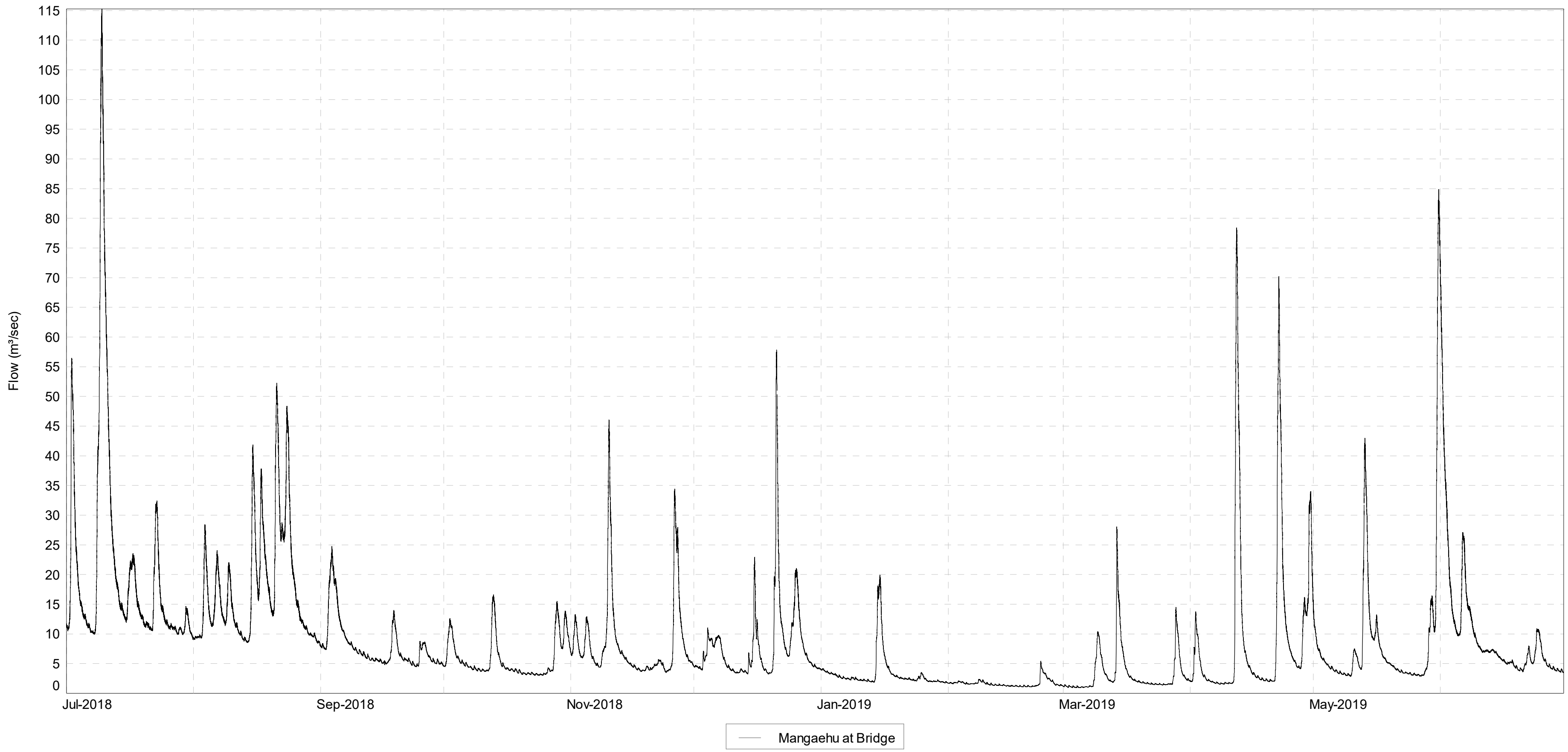


Synthetic Inflow (m3/sec)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Sample Dates

Source is R:\PROCESSING-FILE\TRUSTPOWER-DATA.hts
Synthetic Inflow (m3/sec) at Patea Dam
From 1-Jul-2018 00:00:00 to 30-Jun-2019 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2018-2019 Synthetic Inflow(m3/sec) at Patea Dam

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	28.928	18.813	14.933	13.574	14.381	8.362	7.152	3.129	2.354	14.528	21.044	94.043	
2	71.022	17.201	28.804	18.781	17.829	8.088	6.520	3.163	2.204	19.027	14.887	58.650	
3	39.224	32.740	38.912	14.290	11.507	10.904	6.098	3.377	2.124	9.847	12.259	34.763	
4	26.609	29.270	35.601	10.438	16.121	19.492	5.655	3.276	2.065	5.610	10.556	24.461	
5	22.303	21.106	25.984	9.228	15.836	15.869	5.173	2.977	2.020	4.451	9.351	22.372	
6	19.673	34.376	22.399	8.549	10.358	17.421	4.839	2.871	2.111	3.942	8.376	45.746	
7	18.359	29.159	18.507	7.847	8.856	15.720	4.620	3.020	2.209	3.599	7.701	32.172	
8	58.323	25.141	16.562	7.530	10.287	11.100	4.635	3.560	7.415	3.391	7.145	25.698	
9	163.182	35.791	14.865	7.169	19.387	9.156	4.450	3.420	14.091	3.488	6.755	19.938	
10	114.085	26.519	13.770	6.930	52.770	8.233	4.149	2.928	8.771	3.381	13.347	16.697	
11	67.924	20.983	12.879	6.892	21.658	7.520	4.112	2.731	5.052	11.660	12.683	14.975	
12	42.874	18.503	11.895	20.282	14.125	7.815	3.912	2.615	3.689	109.135	17.077	14.880	
13	32.142	16.839	11.116	24.972	12.003	7.344	3.685	2.591	5.058	36.392	67.203	14.780	
14	26.369	19.146	10.793	12.245	10.454	9.008	13.992	2.544	26.451	14.846	37.629	14.008	
15	24.971	54.323	10.372	9.372	9.198	18.666	25.432	2.407	12.099	10.267	22.268	12.533	
16	37.642	34.038	9.822	8.404	8.421	15.959	10.853	2.361	6.519	8.018	22.254	11.360	
17	37.472	48.303	12.744	7.996	7.669	9.345	7.134	2.328	4.557	6.770	16.450	10.652	
18	27.489	39.196	24.198	7.684	7.288	7.058	5.535	2.256	3.803	5.954	13.193	10.614	
19	23.410	29.109	17.127	7.160	7.758	6.373	4.969	2.264	3.445	5.457	11.551	9.218	
20	21.177	48.601	11.914	6.690	7.494	20.456	4.597	2.274	3.194	5.111	10.288	8.476	
21	19.938	78.501	10.754	6.568	8.515	50.645	4.349	2.226	3.022	11.176	9.092	15.861	
22	43.123	48.627	10.296	6.471	9.330	17.491	4.248	2.726	2.898	90.925	8.307	15.209	
23	38.639	60.001	9.316	6.210	8.080	11.642	3.942	5.796	2.841	51.610	7.855	12.942	
24	24.293	53.315	8.859	6.071	6.968	14.665	4.218	5.452	2.784	23.653	7.550	19.799	
25	21.015	33.852	13.284	6.080	9.545	26.903	5.060	4.109	2.722	16.352	7.079	16.947	
26	19.868	26.323	13.446	6.983	43.025	25.411	4.130	3.329	2.943	12.705	6.800	12.308	
27	18.963	22.090	10.721	10.722	27.045	14.436	3.612	2.651	6.205	10.588	6.576	10.605	
28	18.423	19.856	9.579	25.687	14.755	10.776	3.584	2.504	18.180	23.587	8.197	9.682	
29	18.130	20.863	9.214	16.283	10.610	9.005	3.609		10.513	33.888	21.034	8.969	
30	21.748	20.284	8.723	19.037	9.084	8.125	3.415		5.317	45.932	36.695	?	
31	17.073	16.335		15.318		7.540	3.271		4.182		123.908		
Min	17.073	16.335	8.723	6.071	6.968	6.373	3.271	2.226	2.020	3.381	6.576	8.476	2.020
Mean	37.561	32.232	15.580	11.015	14.345	13.888	5.837	3.032	5.833	20.176	18.874	21.323	16.727
Max	163.182	78.501	38.912	25.687	52.770	50.645	25.432	5.796	26.451	109.135	123.908	94.043	163.182

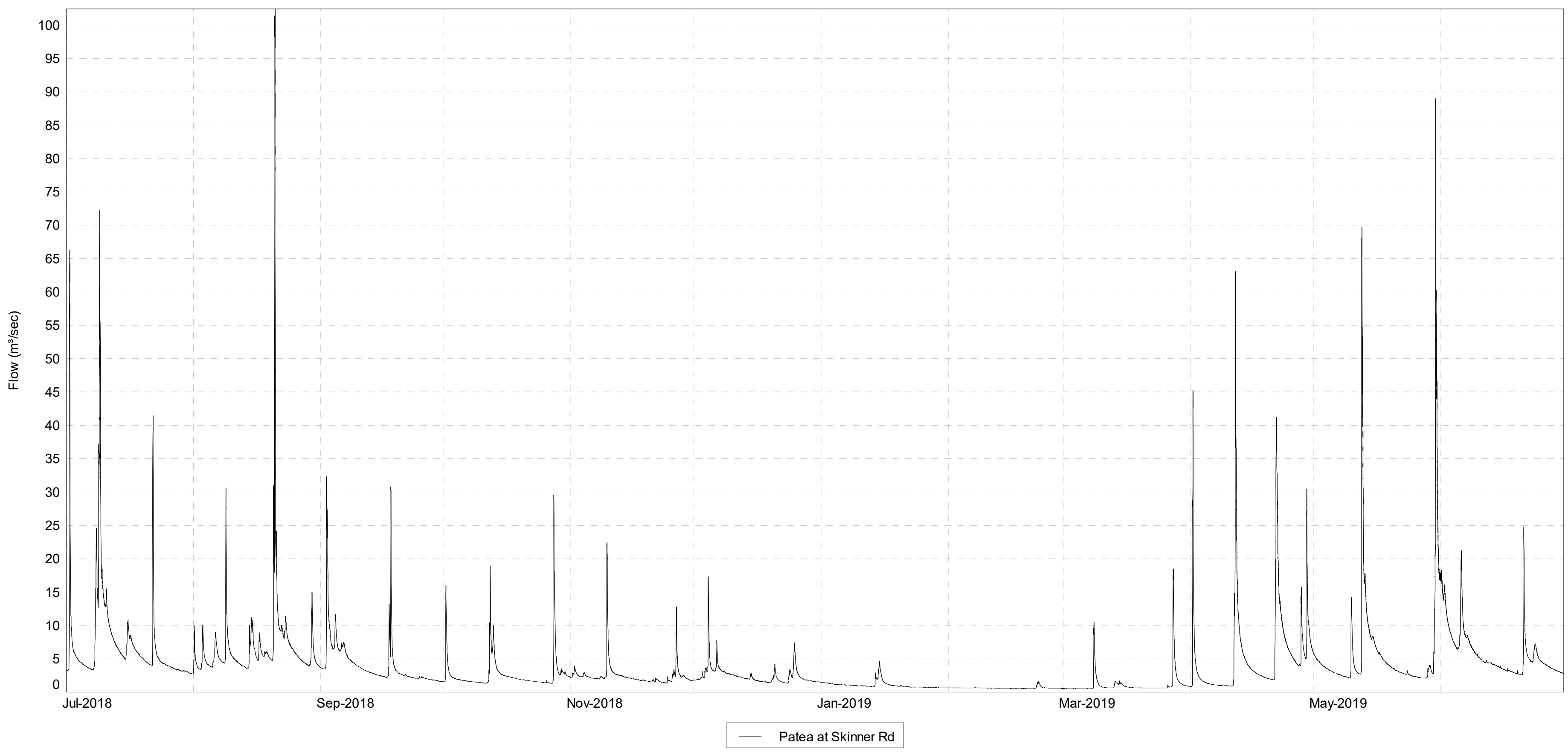


Flow (m³/sec)
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Mangaehu at Bridge

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m^3/sec) at Mangaehu at Bridge
From 1-Jul-2018 00:00:00 to 30-Jun-2019 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2018-2019 Flow(m^3/sec) at Mangaehu at Bridge

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	12.015	9.350	7.883	5.563	8.256	4.524	3.962	1.725	1.244	2.906	10.689	54.181	
2	43.989	9.524	9.813	11.095	10.408	4.213	3.580	1.755	1.142	10.100	7.024	31.752	
3	23.615	18.688	21.261	8.462	6.346	5.721	3.337	1.911	1.083	5.338	5.646	17.639	
4	15.417	17.408	18.966	5.925	9.528	8.910	3.105	1.842	1.045	2.786	4.779	11.742	
5	12.754	11.935	13.347	5.175	9.455	8.530	2.790	1.638	1.018	2.156	4.212	10.086	
6	11.167	19.321	10.450	4.778	5.735	9.114	2.585	1.568	1.077	1.902	3.750	22.612	
7	10.249	16.799	8.866	4.340	4.743	8.480	2.457	1.647	1.146	1.734	3.449	16.357	
8	28.651	12.342	8.130	4.180	5.669	5.526	2.512	2.048	2.605	1.626	3.227	12.811	
9	92.745	18.346	7.327	3.970	10.146	4.347	2.412	1.960	8.769	1.679	3.096	9.545	
10	70.171	14.583	6.882	3.857	33.468	3.843	2.231	1.621	5.560	1.693	4.601	7.824	
11	40.022	11.286	6.527	3.818	12.990	3.494	2.208	1.482	3.048	5.578	6.444	7.073	
12	24.155	9.927	6.052	8.539	8.010	3.823	2.115	1.407	2.126	59.556	4.601	7.125	
13	17.632	9.050	5.679	12.990	6.673	3.629	1.970	1.390	2.889	19.730	30.396	7.189	
14	14.330	9.629	5.608	6.287	5.700	4.815	8.760	1.358	17.897	6.685	18.556	6.824	
15	13.005	32.257	5.436	4.659	4.924	11.838	15.556	1.268	7.621	4.332	9.539	6.013	
16	20.103	19.983	5.184	4.126	4.475	9.912	6.519	1.244	3.982	3.236	10.771	5.449	
17	21.316	29.456	5.398	3.955	4.038	5.373	4.158	1.227	2.692	2.690	7.390	5.076	
18	14.974	23.354	10.576	3.841	3.816	3.841	3.152	1.176	2.187	2.359	5.773	5.167	
19	12.646	16.547	9.601	3.598	4.235	3.415	2.818	1.178	1.951	2.204	5.064	4.344	
20	11.540	17.378	6.356	3.339	4.110	13.160	2.570	1.182	1.786	2.106	4.541	3.969	
21	10.962	43.487	5.684	3.312	4.673	34.167	2.454	1.157	1.671	3.121	3.978	4.464	
22	22.244	27.353	5.502	3.312	5.333	11.204	2.405	1.292	1.588	47.520	3.635	6.697	
23	23.331	35.847	4.932	3.192	4.601	7.197	2.222	3.333	1.551	28.090	3.441	5.322	
24	13.859	32.002	4.702	3.145	3.758	8.522	2.420	3.355	1.514	10.970	3.312	9.281	
25	11.817	19.206	7.817	3.221	5.507	15.796	3.038	2.457	1.471	7.045	3.177	8.338	
26	11.217	14.542	7.943	3.843	27.272	15.814	2.383	1.924	1.512	5.308	3.082	5.468	
27	10.805	12.043	6.113	4.381	16.725	8.643	2.033	1.446	1.827	4.358	3.023	4.565	
28	10.549	10.837	5.405	13.012	8.616	6.256	2.019	1.344	9.467	10.736	4.165	4.179	
29	10.481	9.889	5.239	9.267	6.000	5.091	2.044		6.241	15.884	12.385	3.903	
30	13.114	9.538	4.966	11.433	5.074	4.540	1.917		2.928	26.684	13.294	3.746	
31	9.970	8.512		9.013		4.181	1.820		2.270		67.289		
Min	9.970	8.512	4.702	3.145	3.758	3.415	1.820	1.157	1.018	1.626	3.023	3.746	1.018
Mean	21.253	17.756	7.922	5.794	8.343	7.997	3.340	1.676	3.320	10.004	8.849	10.291	8.935
Max	92.745	43.487	21.261	13.012	33.468	34.167	15.556	3.355	17.897	59.556	67.289	54.181	92.745


Flow (m³/sec)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Jul-2018
Sep-2018
Nov-2018
Jan-2019
Mar-2019
May-2019
Patea at Skinner Rd

Source is R:\ARCHIVES\HYDRO-ARCHIVES.HTS
Flow (m³/sec) at Patea at Skinner Rd
From 1-Jul-2018 00:00:00 to 30-Jun-2019 24:00:00
24 hour periods beginning at midnight each day.

Daily means Years 2018-2019 Flow(m³/sec) at Patea at Skinner Rd

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	
1	12.143	5.251	3.521	5.512	2.764	1.851	1.447	0.648	0.554	10.083	5.327	15.846	
2	8.066	3.543	14.319	2.873	2.787	2.027	1.361	0.645	0.548	4.098	4.517	12.251	
3	5.230	6.294	8.135	2.109	2.363	2.731	1.287	0.639	0.552	2.002	3.912	8.821	
4	4.454	4.184	8.205	1.915	2.638	6.479	1.176	0.628	0.547	1.516	3.475	7.154	
5	3.984	4.060	6.461	1.789	2.241	3.472	1.148	0.619	0.542	1.288	3.113	8.004	
6	3.626	6.868	7.017	1.676	2.082	4.319	1.103	0.615	0.549	1.151	2.819	12.654	
7	3.893	4.904	5.438	1.597	2.004	3.389	1.070	0.653	0.552	1.058	2.594	8.226	
8	18.883	8.076	4.659	1.520	2.192	3.003	1.015	0.634	3.655	1.015	2.372	6.911	
9	30.056	8.455	4.147	1.457	5.587	2.766	0.969	0.608	1.579	1.030	2.189	5.880	
10	13.461	5.350	3.734	1.387	4.842	2.574	0.933	0.595	0.797	0.918	6.476	5.161	
11	10.125	4.646	3.372	1.448	2.892	2.378	0.923	0.594	0.682	5.901	3.215	4.586	
12	7.949	4.137	3.089	8.104	2.589	2.233	0.859	0.586	0.639	22.308	12.477	4.452	
13	6.617	3.760	2.863	5.807	2.391	2.044	0.841	0.586	1.091	7.091	20.700	4.275	
14	5.647	5.498	2.664	3.020	2.221	2.116	1.969	0.583	1.318	4.829	9.919	4.014	
15	6.492	8.533	2.493	2.561	2.076	2.061	3.127	0.572	1.162	3.743	8.018	3.710	
16	8.590	5.334	2.319	2.374	1.942	1.732	1.447	0.561	0.801	3.127	6.417	3.366	
17	6.779	6.550	4.929	2.224	1.819	1.593	1.154	0.554	0.701	2.700	5.452	3.222	
18	5.802	5.756	8.566	2.083	1.768	1.507	1.004	0.554	0.666	2.390	4.587	3.045	
19	5.118	5.234	3.184	1.917	1.661	1.477	0.919	0.558	0.643	2.142	4.017	2.829	
20	4.534	24.213	2.703	1.826	1.600	2.649	0.902	0.563	0.627	1.957	3.536	2.645	
21	4.145	14.471	2.532	1.751	1.806	1.958	0.829	0.552	0.618	8.426	3.176	8.977	
22	11.405	9.225	2.334	1.661	1.683	1.509	0.793	0.889	0.612	21.488	2.907	5.221	
23	5.045	9.293	2.175	1.580	1.455	1.378	0.750	1.036	0.609	10.248	2.774	5.131	
24	4.358	7.195	2.091	1.510	1.577	2.637	0.767	0.659	0.603	7.300	2.611	6.165	
25	4.022	6.161	2.186	1.429	1.899	4.620	0.734	0.592	0.604	5.782	2.384	4.666	
26	3.767	5.313	2.068	1.460	4.812	2.695	0.705	0.566	0.763	4.709	2.248	4.182	
27	3.459	4.692	1.937	5.133	2.829	2.024	0.695	0.567	4.026	4.076	2.132	3.800	
28	3.316	4.211	1.815	6.104	2.357	1.796	0.688	0.563	4.005	8.049	2.271	3.458	
29	3.170	6.819	1.696	2.908	1.963	1.687	0.677		1.443	11.163	3.546	3.170	
30	3.045	5.858	1.600	2.807	1.780	1.595	0.662		1.069	7.260	19.404	2.933	
31	2.801	3.961		2.337		1.525	0.654		0.901		25.944		
Min	2.801	3.543	1.600	1.387	1.455	1.378	0.654	0.552	0.542	0.918	2.132	2.645	0.542
Mean	7.096	6.705	4.075	2.641	2.421	2.446	1.052	0.622	1.079	5.628	5.953	5.825	3.814
Max	30.056	24.213	14.319	8.104	5.587	6.479	3.127	1.036	4.026	22.308	25.944	15.846	30.056

Appendix II

TRC Lake Rotorangi water quality trend analysis 1990-2017

Memorandum

To	K Blakemore, Technical Officer
From	K Blakemore, Technical Officer
Document	#2483642
Date	24/04/2020

Lake Rotorangi trend analysis January 1990 to December 2018

Introduction

A trend analysis of Lake Rotorangi monitoring data from 1990 to 2018 has been undertaken to update analysis conducted by Burns (2006) for data from 1990-2006. This memo provides very little interpretation of the trend analysis, but reproduces analyses provided in the previous report by Burns (2006).

Methods of analysis

The methods of data analysis used are those recommended in the "Protocol for Monitoring New Zealand Lakes (Burns et. al., 2000) that has been published by the Ministry for the Environment. The calculations and plots have been performed using the computer programme, LakeWatch. Refer to Burns (2006) for a more detailed explanation of the methods.

Results and discussion

Table 1 summarises the results of the trend analysis of parameters for each individual site (L2 and L3) as well as both sites combined in Appendix 1.

Table **3** provides the *p* and R values for these trends.

This trend analysis indicates that, while many of the parameters are not significantly changing over time, there is very significant ($p<0.01$) deterioration in nitrate nitrogen at both sites individually and in combination; and significant deterioration ($p<0.05$) in chlorophyll a at site L2 and site L3, and very significant deterioration in chlorophyll when the sites are considered together. The Percent Annual Change (PAC) was calculated for those trends which were significant (PAC=slope/period average*100) and indicated that, when data from sites L2 and L3 are combined, nitrate nitrogen is increasing by 1.7% per year (or 6.4 mgN/m^3/y) and chlorophyll *a* is increasing by 1.8% per year (0.06 mg/m^3/y).

There is also a significant increasing trend in total phosphorus when data from both sites are combined, but not when they are considered individually. The PAC was calculated and indicated that, when data from sites L2 and L3 are combined, total phosphorus is increasing by 2.8% per year (or 0.96 mgP/m^3/y).

Figure 1, Figure 2 and Figure 3 present the significant trends graphically for the combined sites' data. Trends are presented graphically for all parameters for combined sites (Appendix 2) and individual sites (Appendices 3 and 4).

Table 1 Trends in water quality parameters in Lake Rotorangi for monitoring conducted from 1990 to 2018

Parameter	L2	L3	L2 & L3
Chlorophyll *a*	☹	☹	☹
DO	😐	😐	😐
EC	😐	😐	😐
Secchi Depth	😐	😐	😐
TSS	😐	😐	😐
Temperature	😐	😐	😐
DRP	😐	😐	😐
NH_4	😐	😐	😐
NO_3	☹	☹	☹
TN	😐	😐	😐
TP	😐	😐	☹
HVOD	😐	😐	😐
TLI	☹	☹	☹

Key:

☺ statistically very significant **improvement** P<0.01 (1%)

☺ statistically significant **improvement** P<0.05 (1%)

😐 **no statistically significant change**

☹ statistically significant **deterioration** P<0.05 (5%)

☹ statistically very significant **deterioration** P<0.01 (less than 1% probability that the trend is due to natural variability and doesn't represent an actual change)

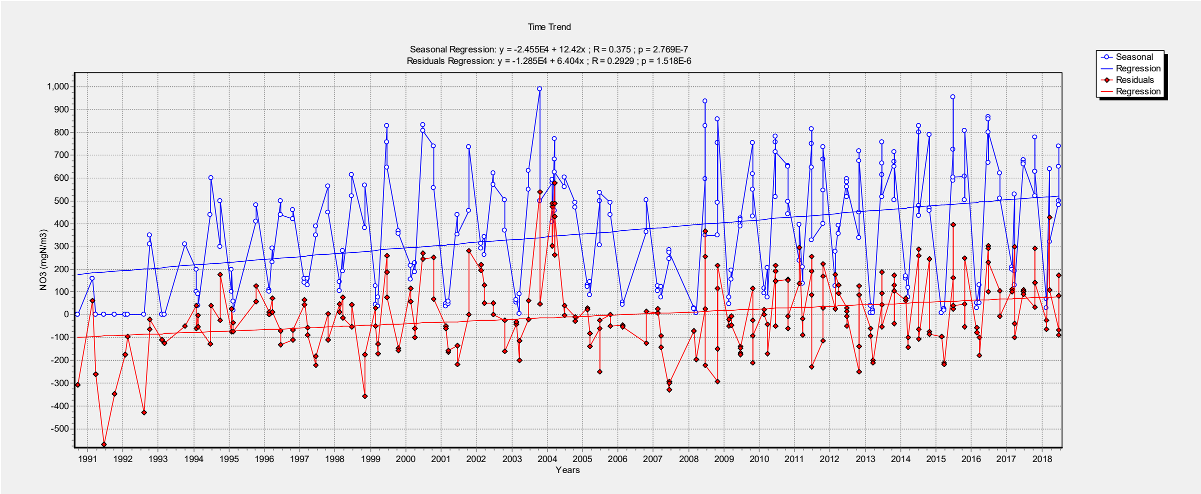


Figure 1: Nitrate nitrogen (NO3) trend line for sites L2 and L3 combined

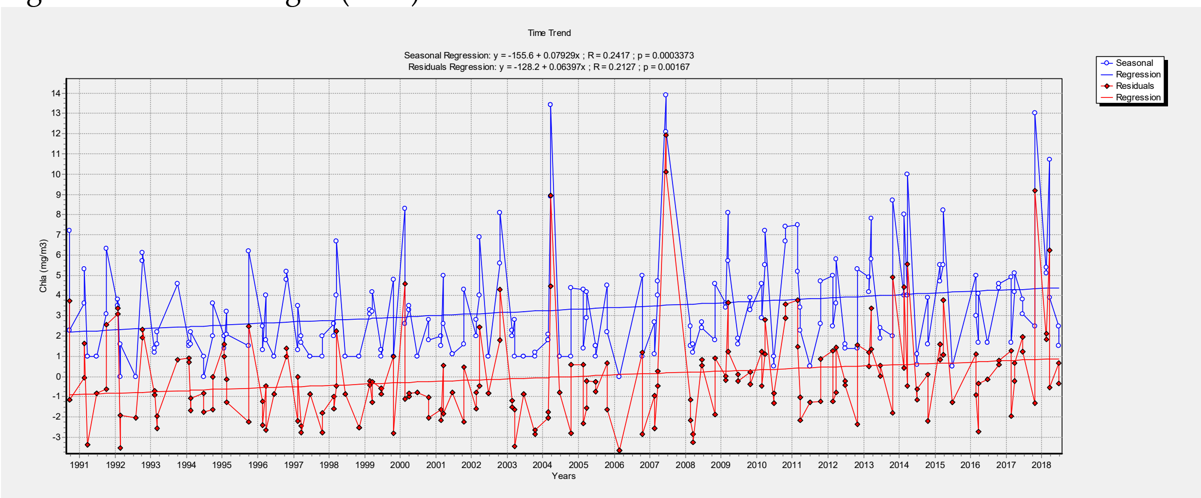


Figure 2: Chlorophyll a trend line for sites L2 and L3 combined

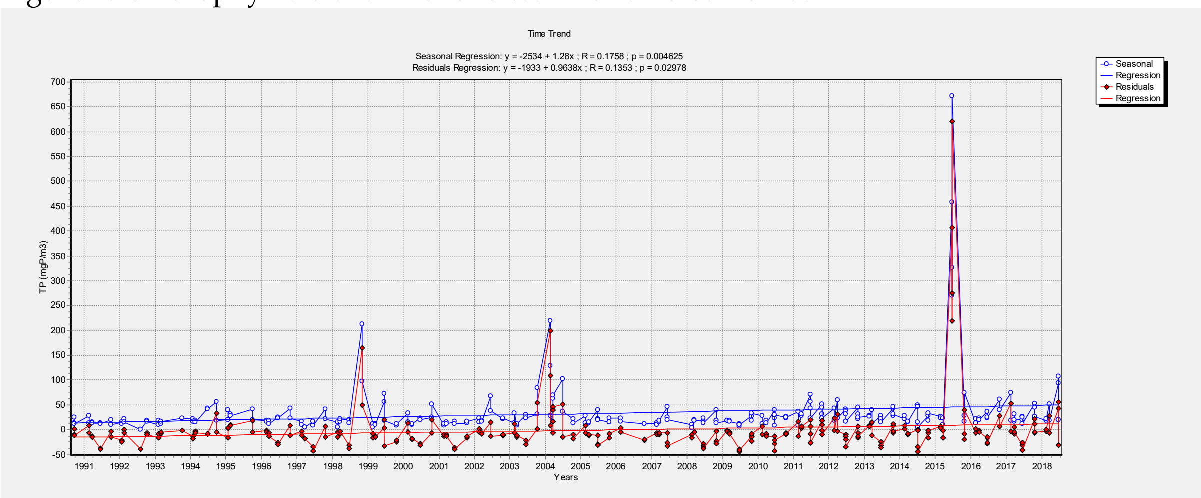


Figure 3: Total phosphorus trend line for sites L2 and L3 combined

The Trophic Level Index (TLI) values are shown in Table 2 for sites L2 and L3 combined. The TLI is calculated by converting the annual average values of chlorophyll a, secchi disc, total phosphorus and total nitrogen into the variable trophic level values of TLc, TLs, TLp and TLn respectively (collectively these are labelled as TLx values) and the averages of these four values gives the annual TLI values. The average of the annual values gives the trophic level of the lake. In a balanced lake, these values are of similar magnitude.

The average TLI for the 1990-2018 period is 4.23 (±0.06) (Table 2 in Appendix 2). This indicates that the lake is eutrophic as per the following table (reproduced from Burns (2006)). However, when the individual key variables are compared with the trophic levels, chlorophyll *a* indicates that the lake is in a mesotrophic state, secchi depth indicates between mesotrophic and eutrophic states, and nutrients indicate a eutrophic state (see highlighted areas in Table 2).

When the sites are looked at individually the TLI of L2 continues to be slightly eutrophic; however L3 is within the mesotrophic boundary. Therefore site L2 continues to be more eutrophic at a TLI of 4.32 (possibly as a result of this site's proximity to the upper catchment) due to the higher total phosphorus and nitrogen levels and lower secchi depth (refer to Appendices 3 and 4). The L2 TLI for chlorophyll *a* indicated a mesotrophic state. The L3 TLI (3.93) indicated mesotrophic conditions in the 2018 year of monitoring.

In 2018, the TLI was found to have a highly significant increase over time for the two sites combined ($p<0.01$), although the magnitude of the change was small (0.02 ±0.01 TLI units per year). When the sites were considered individually, both sites recorded a significant increase in TLI, again with increases being of a small magnitude (0.02 ±0.01 TLI units per year at both sites). When the PAC is considered, the two sites individually show no change, while the combined data shows probable degradation. Although in previous years, significant changes in TLI have not been recorded, in Burns' (2006) report, he notes that while there are no 'significant' trends in the trophic level or the average concentrations of the key variables (Chl *a*, Secchi, TP, TN), there are some insignificant increases in these variables; and coupled with a significant trend for NO_3, suggests that the trophic level is increasing, albeit at a very small rate of change (0.01 ±0.01 units per year), which he notes is not a cause for major concern. The current trend analysis continues to support this conclusion.

Table 2 Values of key variables that define the boundaries of different Trophic Levels (highlighted areas relate to the status of Lake Rotorangi using 1990-2018 data)

Lake Type	Trophic Level	Chl a (mg m^{-3})	Secchi Depth (m)	TP (mg P m^{-3})	TN (mg N m^{-3})
Ultra-microtrophic	0.0 - 1.0	0.13 - 0.33	33 - 25	0.84 - 1.8	16 - 34
Microtrophic	1.0 to 2.0	0.33 - 0.82	25 -15	1.8 - 4.1	34 73
Oligotrophic	2.0 to 3.0	0.82 - 2.0	15 - 7.0	4.1 - 9.0	73 -157
Mesotrophic	3.0 to 4.0	2.0 - 5.0	7.0 - 2.8	9.0 - 20	157 - 337
Eutrophic	4.0 to 5.0	5.0 - 12	2.8 - 1.1	20 - 43	337 - 725
Supertrophic	5.0 to 6.0	12 - 31.0	1.1 - 0.4	43 - 96	725 -1558
Hypertrophic	6.0 to 7.0	>31	<0.4	>96	>1558

Hypolimnetic Volumetric Oxygen Depletion (HVOD) has been calculated for sites L2 and L3 using the 'Lakewatch' programme. The hypolimnion depths have been fitted to dissolved oxygen profiles for each year of analysis in the summer monitoring months of February and March; these values are based on recommendations by the Job Manager from past assessments of the stratification depth profiles. The HVOD *p* values indicate that there has been no significant change over the 1990-2018 period. Furthermore the HVOD parameter has been the subject of discussion at a national level and it has not been recommended for annual use in future national monitoring and reporting (NIWA, 2011). While TRC currently provides a yearly HVOD summary, on the basis of work currently being undertaken by NIWA and MfE, it may not be applicable for future HVOD analysis of Lake Rotorangi data. There have also been discrepancies over HVOD data currently stored in Lakewatch due to some difficulties with using the software in the 2013-2015 analysis; interpretation of these data should be viewed with caution. TRC will continue to be updated with national monitoring protocols and follow any guidance and instruction where necessary when monitoring and reporting on Lake Rotorangi.

Table 3 *p* and R values for trend analysis of 1990-2018 data at sites L2 and L3 in Lake Rotorangi

Parameter	L2		L3		L2 & L3	
	p-value	R	*p*-value	R	*p*-value	R
Chlorophyll *a*	0.02	0.23	0.04	0.20	0.002	0.21
DO	0.62	0.05	0.26	-0.11	0.62	-0.03
EC	0.66	0.03	0.31	0.08	0.33	0.05
Secchi Depth	0.98	-0.00	0.36	-0.09	0.48	-0.05
TSS	0.34	0.07	0.25	0.09	0.14	0.08
Temperature	0.48	0.07	0.98	0.00	0.65	0.03
DRP	0.49	0.06	0.48	-0.06	0.98	-0.00
NH_4	0.84	-0.02	0.83	0.02	0.98	-0.00
NO_3	0.0008	0.29	0.0006	0.30	0.000002	0.29
TN	0.58	0.05	0.94	-0.01	0.75	0.02
TP	0.09	0.15	0.17	0.13	0.03	0.14
HVOD	0.56	0.12	0.15	-0.28	0.19	-0.25
TLI	0.03	0.20	0.01	0.26	0.009	0.24

Values in orange = significant trend at p<0.05, values in red = significant trend at p<0.01

References

Burns N.M., 2006: Water quality trends in Lake Rotorangi, 1990-2006. Report prepared for NIWA, October 2006.

Burns N.M., Bowman E and Bryers G., 2000: Protocol for monitoring the trophic levels of New Zealand Lakes and Reservoirs. New Zealand Ministry for the Environment, Wellington, NZ. 138p.

Connolly A, 2011: Lake Rotorangi trend analysis January 1990 to December 2010. TRC Internal Memo.

Connolly A, 2012: Lake Rotorangi trend analysis January 1990 to December 2011. TRC Internal Memo.

Connolly A, 2016: Lake Rotorangi trend analysis January 1990 to December 2015. TRC Internal Memo.

Giles K, 2010: Lake Rotorangi trend analysis January 1990 to December 2009. TRC Internal Memo

Hope K, 2009: Lake Rotorangi trend analysis January 1990 to December 2008. TRC Internal Memo

Hafiz F., 2013: Lake Rotorangi trend analysis January 1990 to December 2012. TRC Internal Memo.

Hafiz F., 2014: Lake Rotorangi trend analysis January 1990 to December 2013. TRC Internal Memo

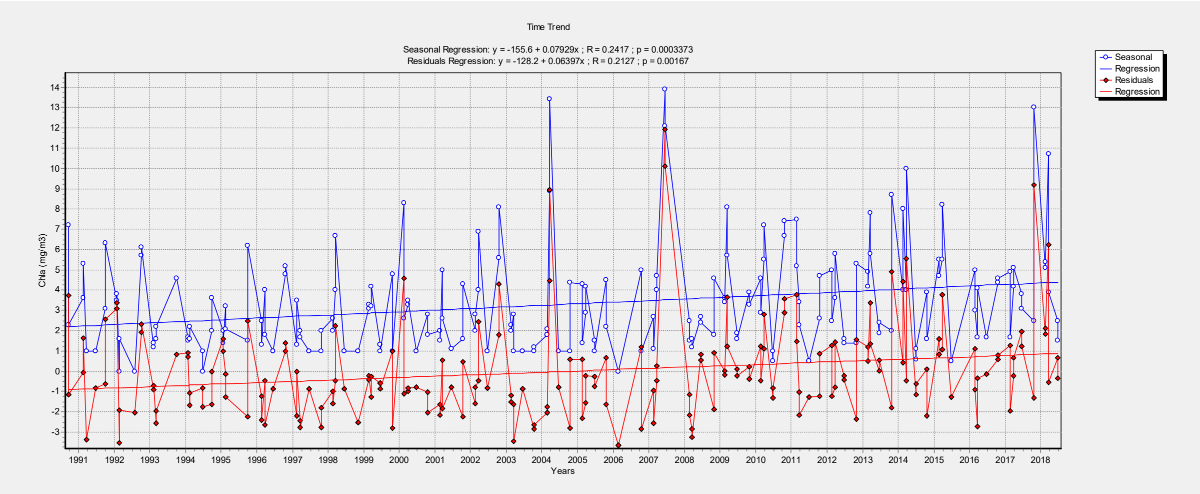
Hafiz F., 2015: Lake Rotorangi trend analysis January 1990 to December 2014. TRC Internal Memo

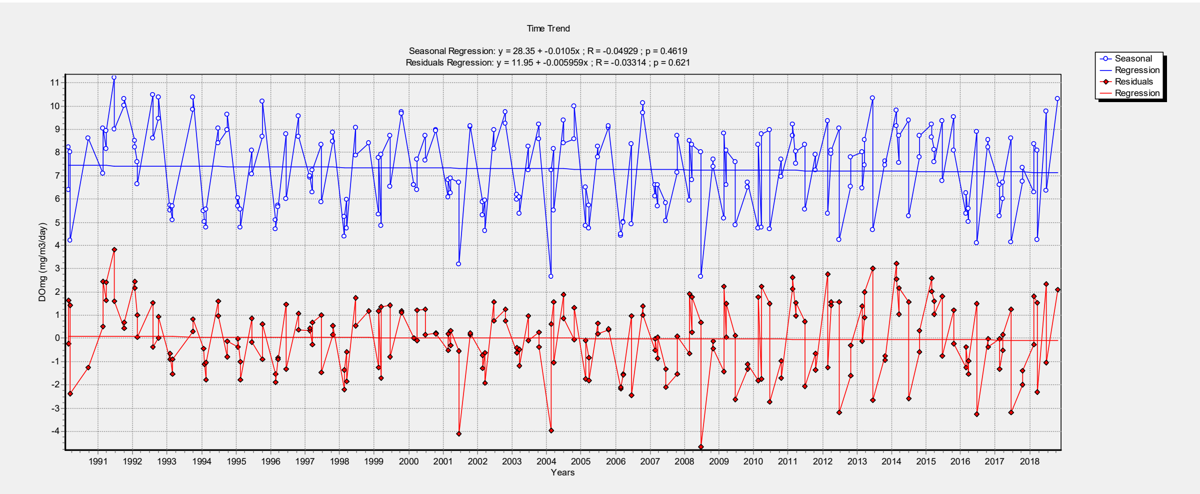
Kitto J., 2019: Lake Rotorangi trend analysis Juanuary 1990 to December 2017. TRC Internal Memo

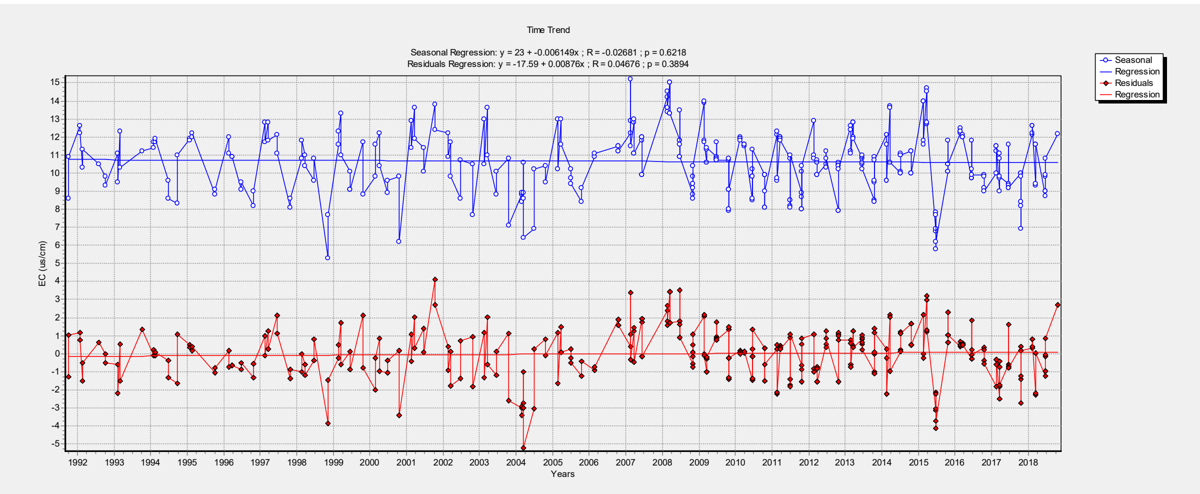
NIWA, 2011: Investigation of single indicators for water quality assessment and reporting- Prepared for the Ministry for the Environment. 108-113p.

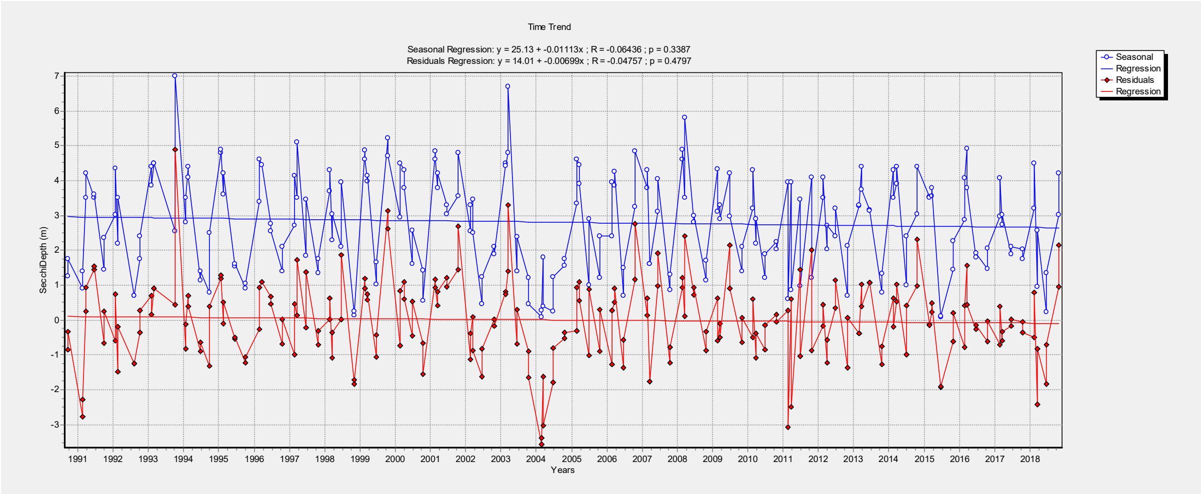
Appendix 2

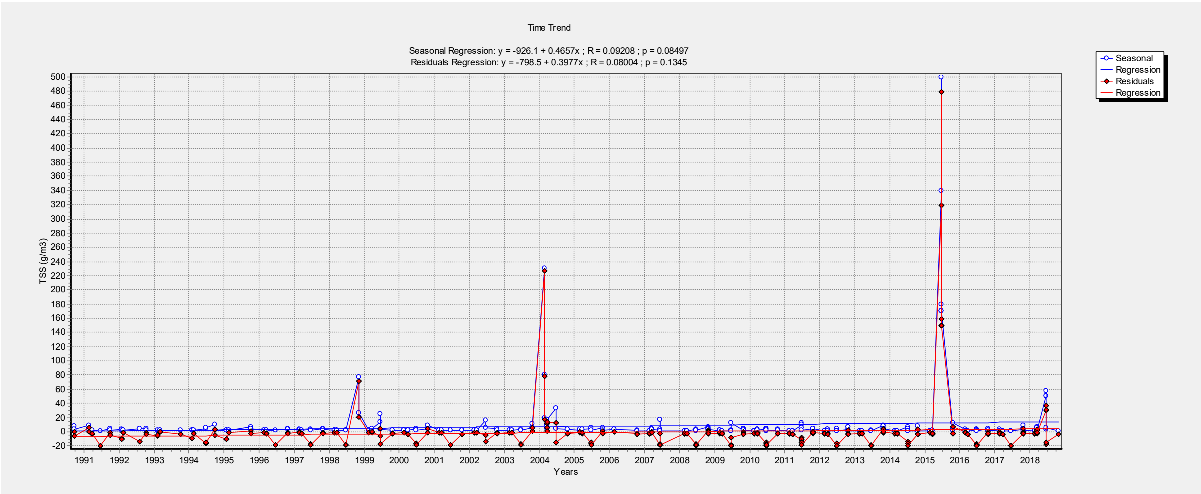
L2 and L3 combined – Physical parameters

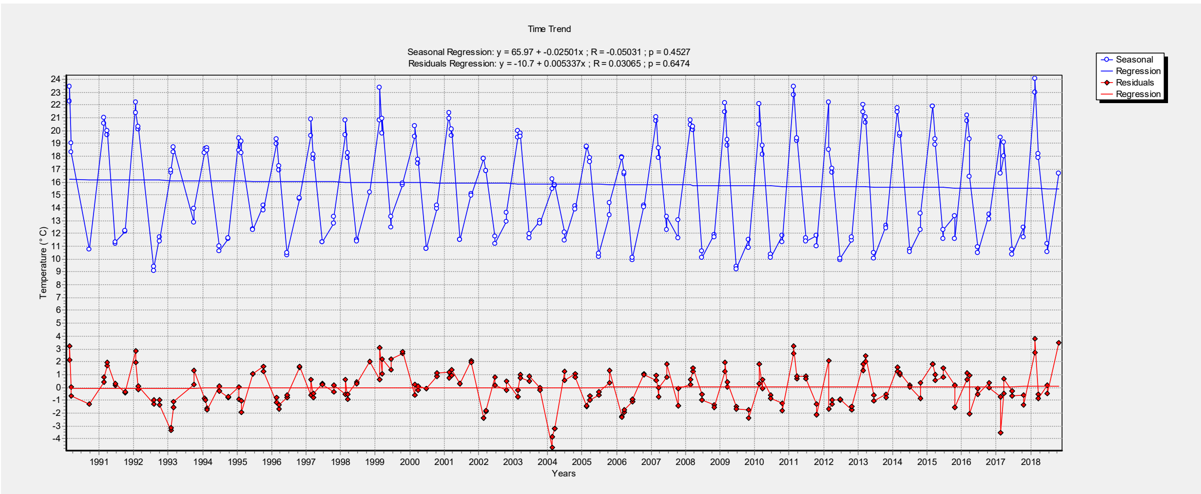




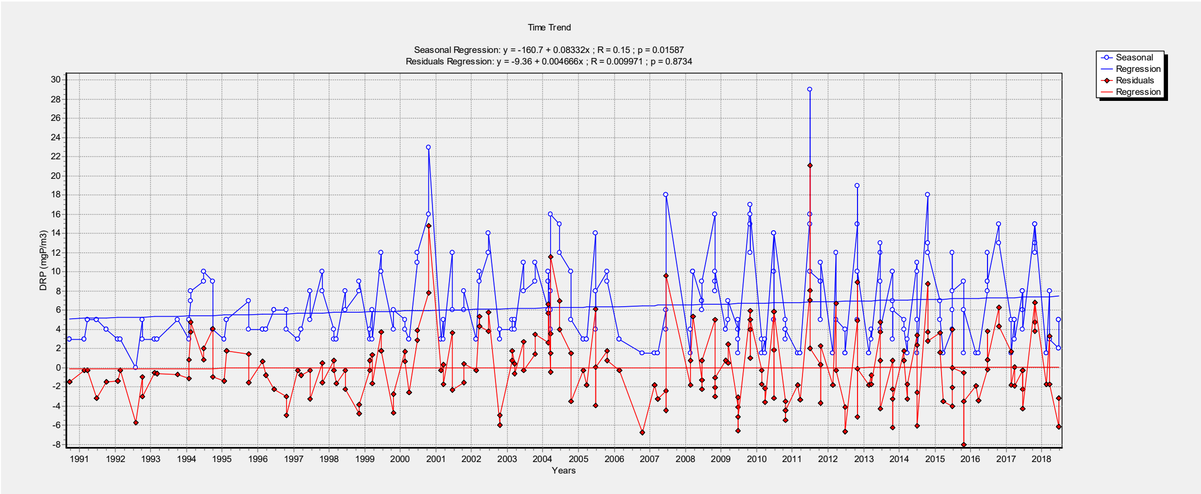


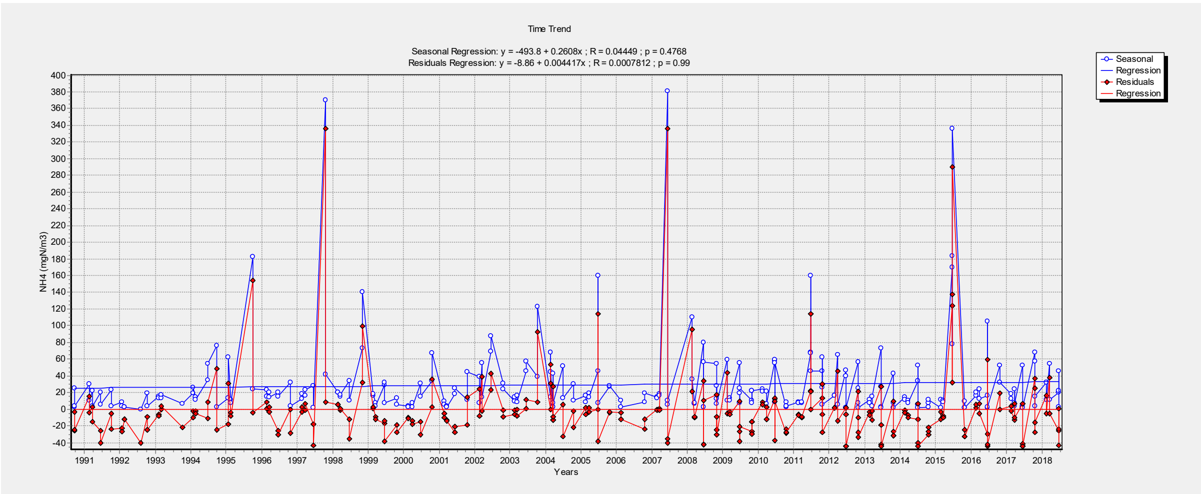

Time Trend
Seasonal Regression: y = 25.13 + -0.01113x ; R = -0.06436 ; p = 0.3387
Residuals Regression: y = 14.01 + -0.00699x ; R = -0.04757 ; p = 0.4797
Seasonal
Regression
Residuals
Regression
Secchi Depth (m)
Years

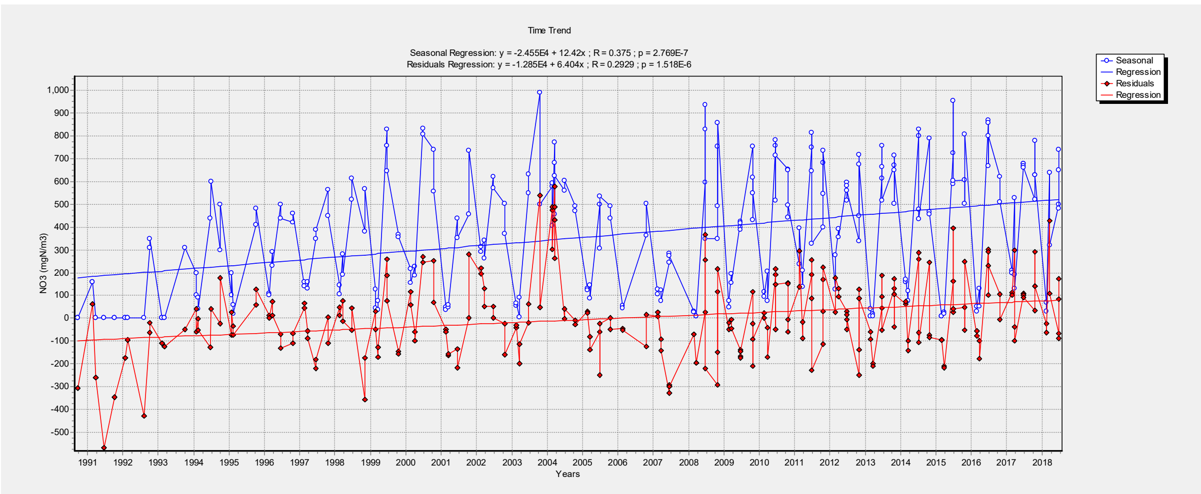

Time Trend
Seasonal Regression: y = -926.1 + 0.4657x ; R = 0.09208 ; p = 0.08497
Residuals Regression: y = -798.5 + 0.3977x ; R = 0.08004 ; p = 0.1345
Seasonal
Regression
Residuals
Regression
TSS (g/m3)
Years

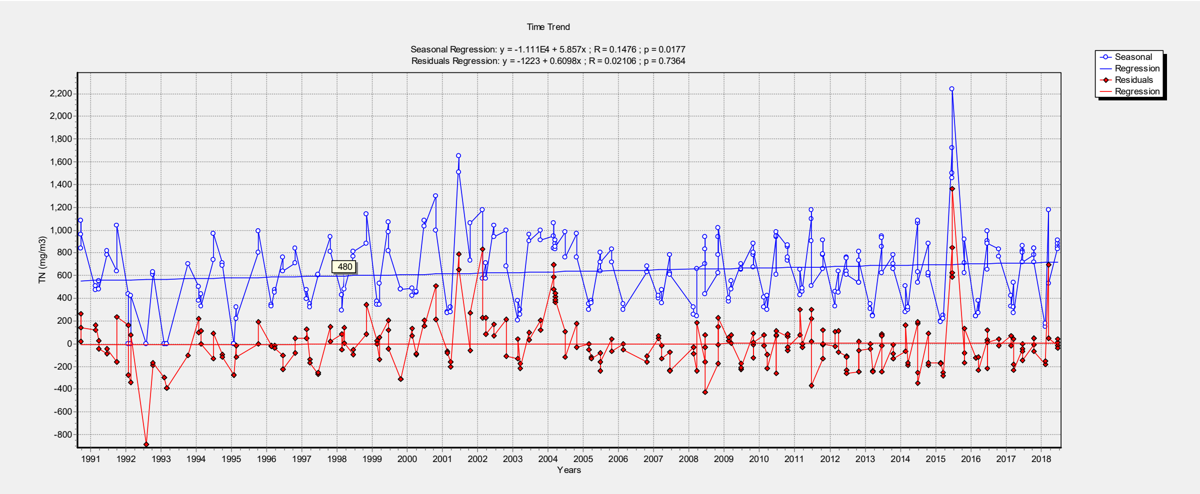

Time Trend
Seasonal Regression: y = 65.97 + -0.02501x ; R = -0.05031 ; p = 0.4527
Residuals Regression: y = -10.7 + 0.005337x ; R = 0.03065 ; p = 0.6474
Seasonal
Regression
Residuals
Regression
Temperature (°C)
Years

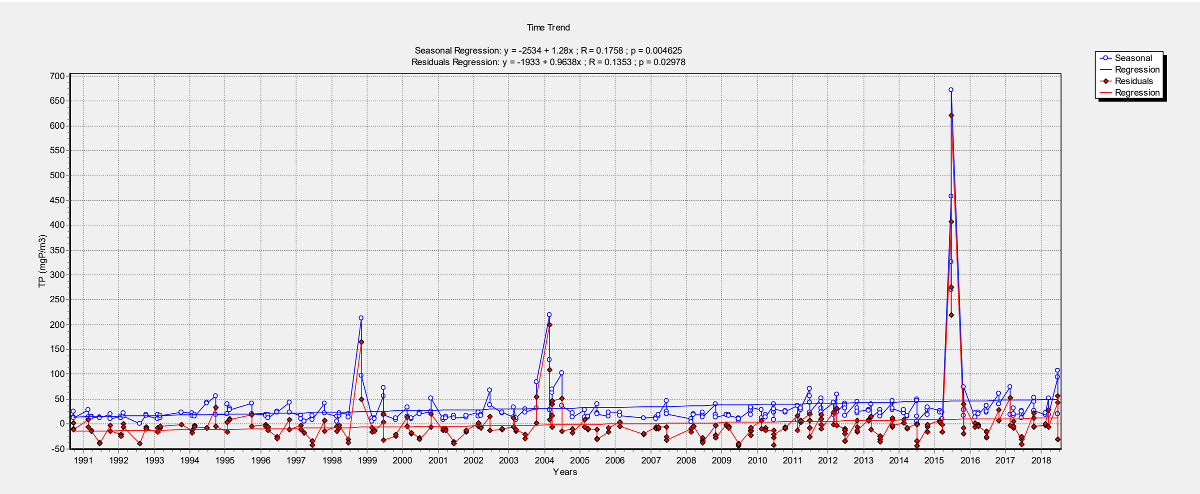
Nutrients- L2 and L3 combined








Time Trend
Seasonal Regression: y = -1.111E4 + 5.857x ; R = 0.1476 ; p = 0.0177
Residuals Regression: y = -1223 + 0.6098x ; R = 0.02106 ; p = 0.7364
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years
480
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
-200
-400
-600
-800
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018


Time Trend
Seasonal Regression: y = -2534 + 1.28x ; R = 0.1758 ; p = 0.004625
Residuals Regression: y = -1933 + 0.9638x ; R = 0.1353 ; p = 0.02978
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd), L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2018

Analysis Period			Average	Observed DO	Observed Rate Corrected to 9.9 °C (mg/m3/day)
01-Jan-1990	-	31-Mar-1990	10.51	1.1	1.0
01-Jan-1991	-	31-Mar-1991	11.59	12.3	10.9
01-Jan-1992	-	30-Mar-1992	9.85	10.1	10.2
01-Jan-1993	-	31-Mar-1993	9.4	-1.2	-1.2
01-Jan-1994	-	31-Mar-1994	8.55	18.8	20.6
01-Jan-1995	-	31-Mar-1995	11.1	40.2	37.0
01-Jan-1996	-	30-Mar-1996	8.94	27.3	29.2
01-Jan-1997	-	31-Mar-1997	8.66	14.5	15.8
01-Jan-1998	-	31-Mar-1998	8.31	5.6	6.3
01-Jan-1999	-	31-Mar-1999	13.32	13.7	10.8
01-Jan-2000	-	04-Apr-2000	10.12	5.6	5.5
01-Jan-2001	-	31-Mar-2001	11.08	16.4	15.1
01-Jan-2002	-	31-Mar-2002	8.73	8.9	9.7
01-Jan-2003	-	31-Mar-2003	9.66	-0.4	-0.4
01-Jan-2005	-	31-Mar-2005	8.94	37.0	39.6
01-Jan-2006	-	31-Mar-2006	9.42	19.1	19.8
01-Jan-2007	-	31-Mar-2007	10.19	5.1	5.0
01-Jan-2008	-	30-Mar-2008	9.49	4.8	4.9
01-Jan-2009	-	31-Mar-2009	10.06	10.2	10.1
01-Jan-2010	-	31-Mar-2010	8.97	-18.0	-19.2
01-Jan-2011	-	31-Mar-2011	10.25	24.0	23.4
01-Jan-2012	-	30-Mar-2012	9.25	-5.4	-5.6
01-Jan-2013	-	31-Mar-2013	9.93	13.0	13.0
01-Jan-2014	-	31-Mar-2014	10.96	8.9	8.3
01-Jan-2015	-	31-Mar-2015	9.63	2.2	2.2
01-Jan-2016	-	30-Mar-2016	9.6	2.8	2.9
01-Jan-2017	-	31-Mar-2017	9.69	10.9	11.1
01-Jan-2018	-	31-Mar-2018	11.08	1.5	1.4
Average			**9.90**	**10.3**	**10.3**

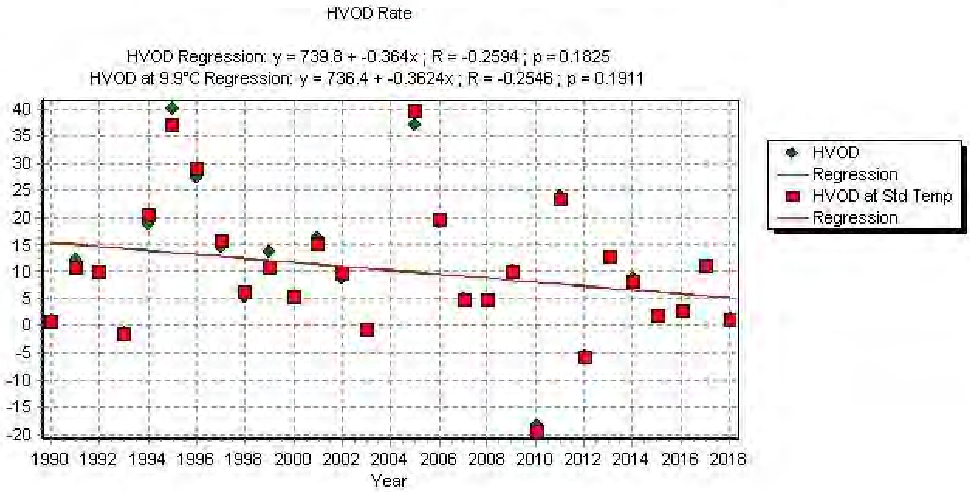
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd), L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2018

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.9 °C (mg/m3/day)



LAKE ROTORANGI

L2 & L3 1990-2019 (1 Jan 1990 - 31 Dec 2018)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.06	(-0.01)	0.96	(0.61)	(-0.36)			
Average Over Period	3.31	(2.80)	33.86	(643.57)	(10.26)			
Percent Annual Change (%/Year)	**1.81**	**0.00**	**2.84**	**0.00**	**0.00**	**0.93**	**0.59**	**0.19**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	3.93	1.50	16.33	960.00	3.73	5.06	3.76	5.37	4.48	0.43			
Jan 1991 - Dec 1991	2.79	2.61	15.88	661.25	3.35	4.40	3.72	4.88	4.09	0.34			
Jan 1992 - Dec 1992	2.96	2.33	14.00	300.00	3.42	4.54	3.56	3.85	3.84	0.25			
Jan 1993 - Dec 1993	2.20	4.47	15.80	140.00	3.09	3.74	3.72	2.85	3.35	0.22			
Jan 1994 - Dec 1994	1.70	2.58	28.75	595.00	2.81	4.41	4.48	4.74	4.11	0.44			
Jan 1995 - Dec 1995	2.73	2.82	30.50	388.33	3.33	4.30	4.55	4.18	4.09	0.27			
Jan 1996 - Dec 1996	2.70	3.04	22.25	567.50	3.32	4.22	4.15	4.68	4.09	0.28			
Jan 1997 - Dec 1997	1.69	2.98	16.00	561.25	2.80	4.24	3.73	4.66	3.86	0.40			
Jan 1998 - Dec 1998	2.41	2.47	50.25	677.50	3.19	4.47	5.19	4.91	4.44	0.44			
Jan 1999 - Dec 1999	2.58	3.77	22.78	601.11	3.26	3.95	4.18	4.75	4.04	0.31			
Jan 2000 - Dec 2000	3.04	2.71	23.50	778.75	3.45	4.35	4.22	5.09	4.28	0.34			
Jan 2001 - Dec 2001	2.40	4.02	12.75	762.50	3.19	3.87	3.45	5.07	3.89	0.42			
Jan 2002 - Dec 2002	3.93	2.19	28.00	836.25	3.73	4.61	4.44	5.19	4.49	0.30			
Jan 2003 - Dec 2003	1.54	3.23	29.63	615.00	2.69	4.14	4.52	4.78	4.03	0.47			
Jan 2004 - Dec 2004	5.25	0.92	67.55	890.00	4.05	5.63	5.56	5.27	5.13	0.37			
Jan 2005 - Dec 2005	2.61	2.97	21.11	566.67	3.28	4.24	4.09	4.68	4.07	0.29			
Jan 2006 - Dec 2006	1.50	3.09	15.75	490.00	2.67	4.19	3.71	4.49	3.77	0.40			
Jan 2007 - Dec 2007	5.01	2.58	25.30	675.00	4.00	4.42	4.32	4.91	4.41	0.19			
Jan 2008 - Dec 2008	2.29	3.43	18.00	645.83	3.13	4.07	3.88	4.85	3.98	0.35			
Jan 2009 - Dec 2009	3.94	3.03	18.08	632.50	3.73	4.22	3.89	4.82	4.16	0.24			
Jan 2010 - Dec 2010	4.47	2.50	22.67	678.33	3.87	4.45	4.18	4.91	4.35	0.22			
Jan 2011 - Dec 2011	3.34	2.39	37.67	738.33	3.55	4.51	4.82	5.02	4.48	0.33			
Jan 2012 - Dec 2012	3.33	2.60	33.00	605.00	3.55	4.41	4.65	4.76	4.34	0.28			
Jan 2013 - Dec 2013	4.71	2.89	29.25	608.33	3.93	4.28	4.50	4.77	4.37	0.18			
Jan 2014 - Dec 2014	4.15	3.37	25.36	620.00	3.79	4.09	4.32	4.80	4.25	0.21			
Jan 2015 - Dec 2015	4.15	2.29	175.45	911.82	3.79	4.56	6.77	5.30	5.10	0.64			
Jan 2016 - Dec 2016	3.28	2.86	30.30	615.00	3.53	4.29	4.54	4.78	4.29	0.27			
Jan 2017 - Dec 2017	4.79	2.57	30.08	635.38	3.95	4.42	4.53	4.83	4.43	0.18			
Jan 2018 - Dec 2018	4.85	2.50	44.13	688.75	3.96	4.45	5.02	4.93	4.59	0.24			
Averages	**3.25**	**2.78**	**31.73**	**636.05**	**3.45**	**4.36**	**4.36**	**4.76**	**4.23**	**0.06**	**0.02**	**0.01**	**0.0091**

SUMMARY:

PAC = 0.93 ± 0.59 % per year
P-Value = 0.19

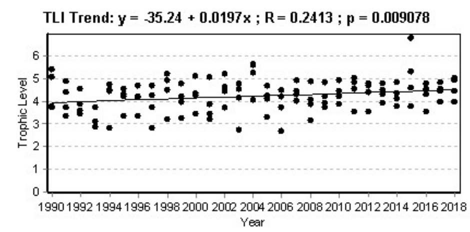
TLI Value = 4.23 ± 0.06 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.0091

ASSESSMENT:

Eutrophic
Probable Degredation

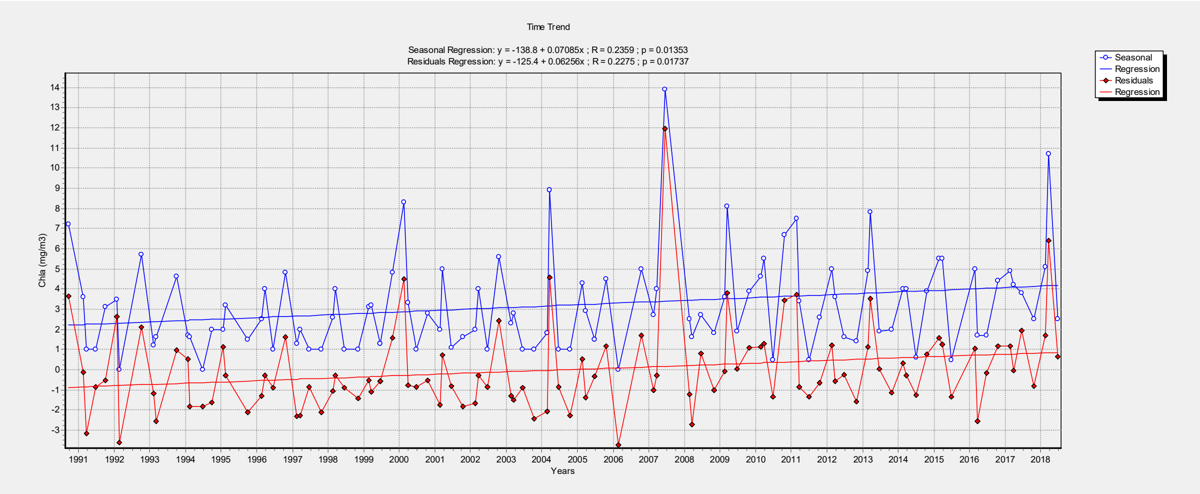
The guide used in the PAC average P-Value evaluation is

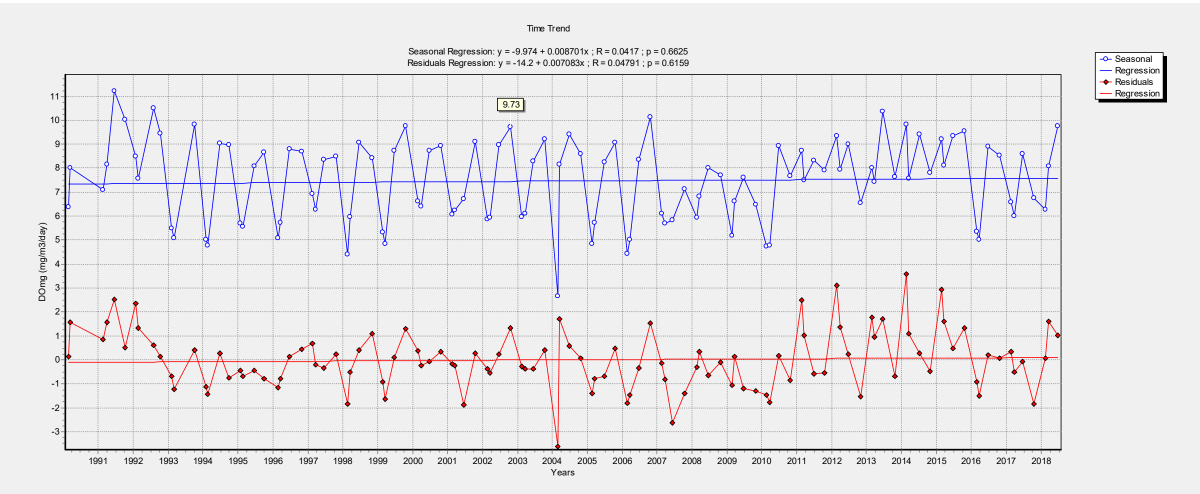
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

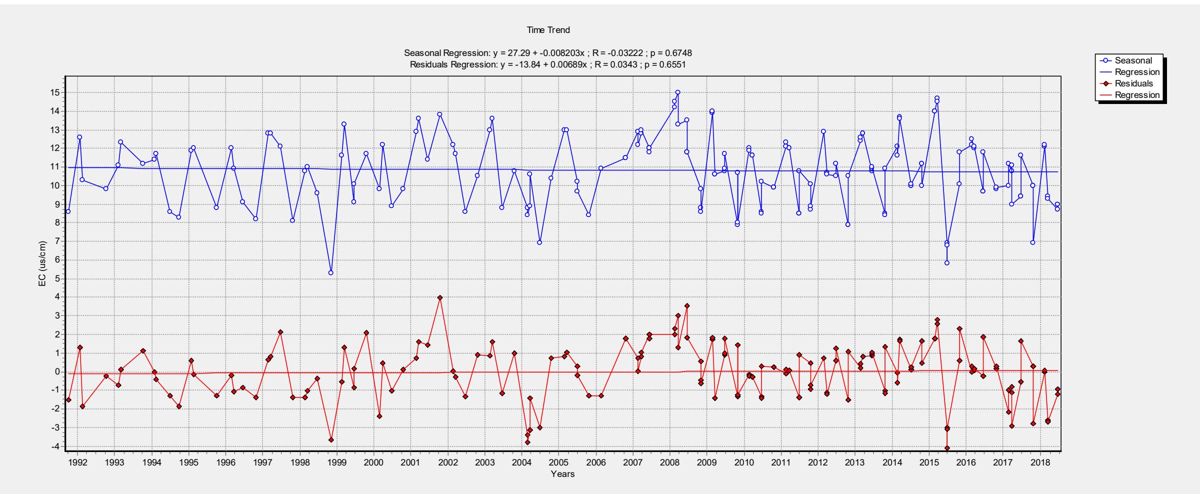


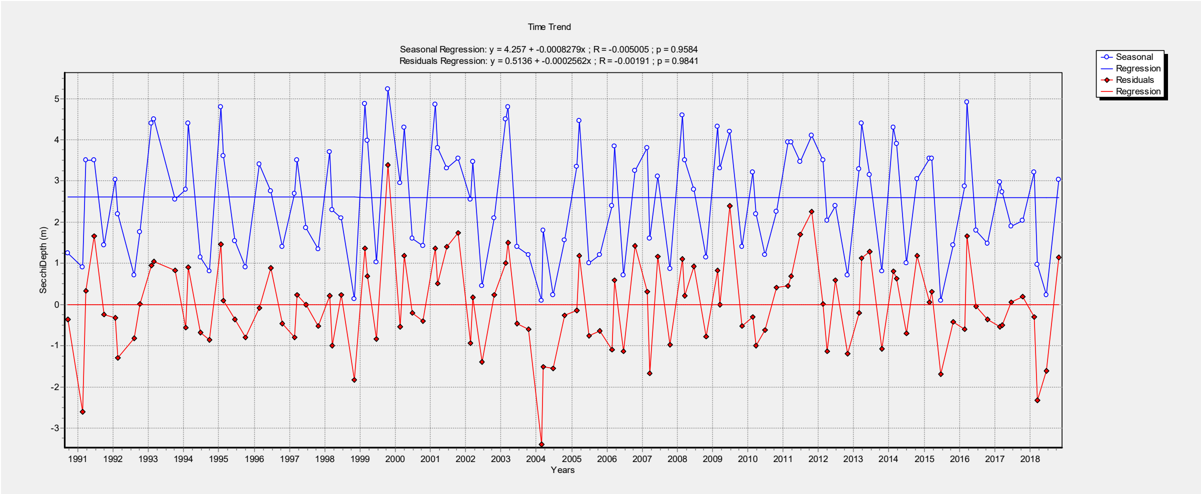
Appendix 3

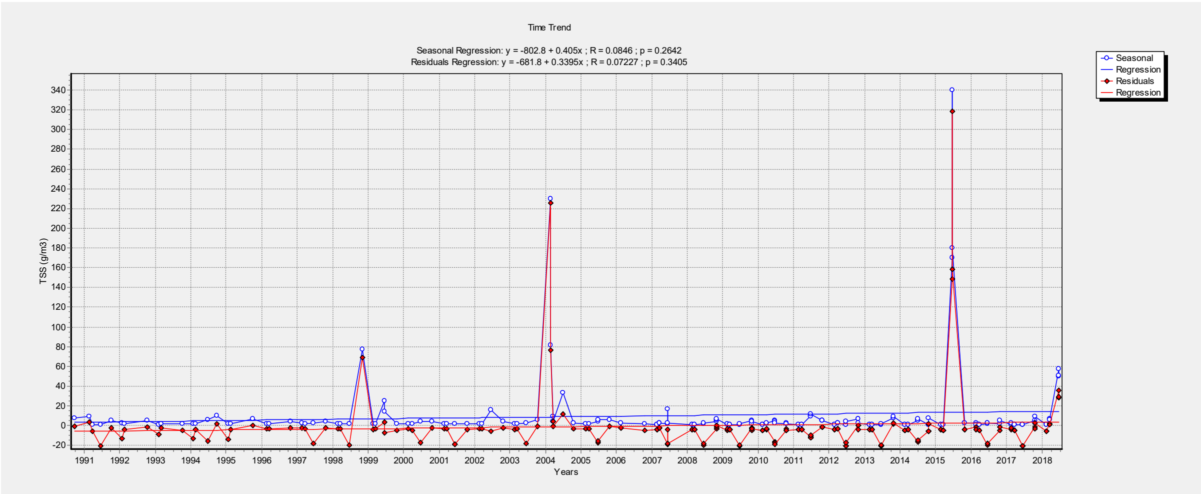
L2 trends – Physical parameters

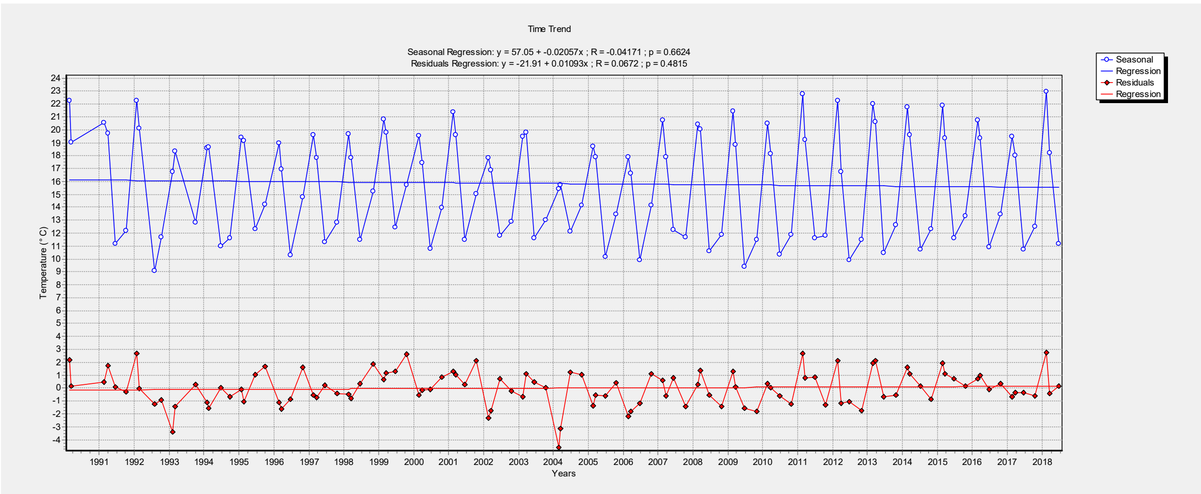




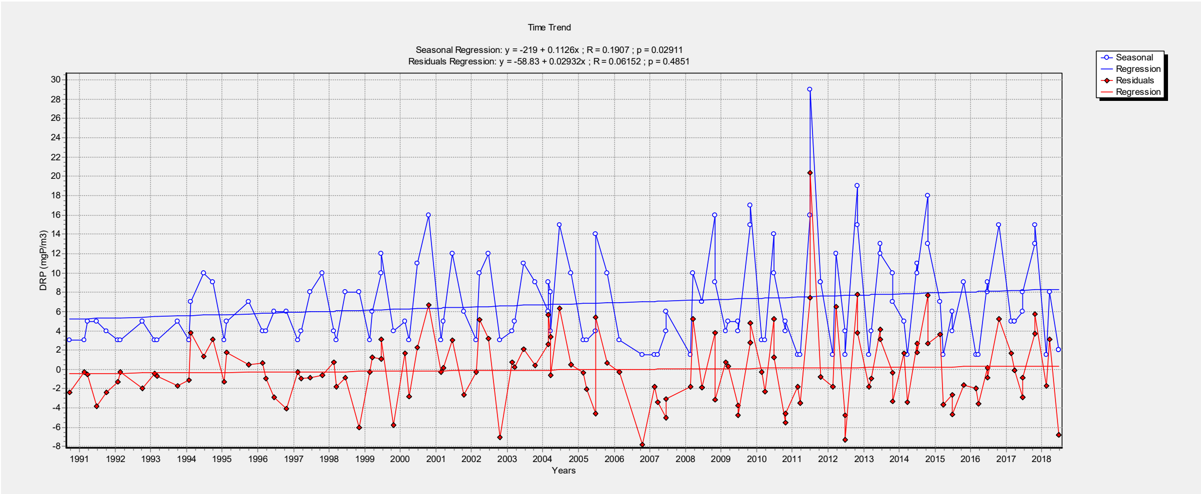


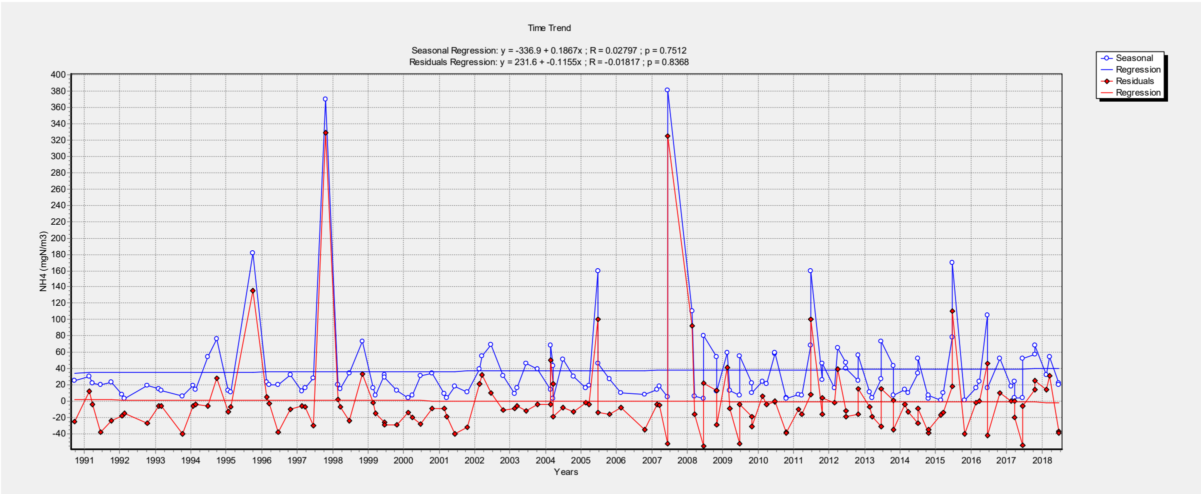

Time Trend
Seasonal Regression: y = 4.257 + -0.0008279x ; R = -0.005005 ; p = 0.9584
Residuals Regression: y = 0.5136 + -0.0002562x ; R = -0.00191 ; p = 0.9841
SecchiDepth (m)
Years
Seasonal
Regression
Residuals
Regression

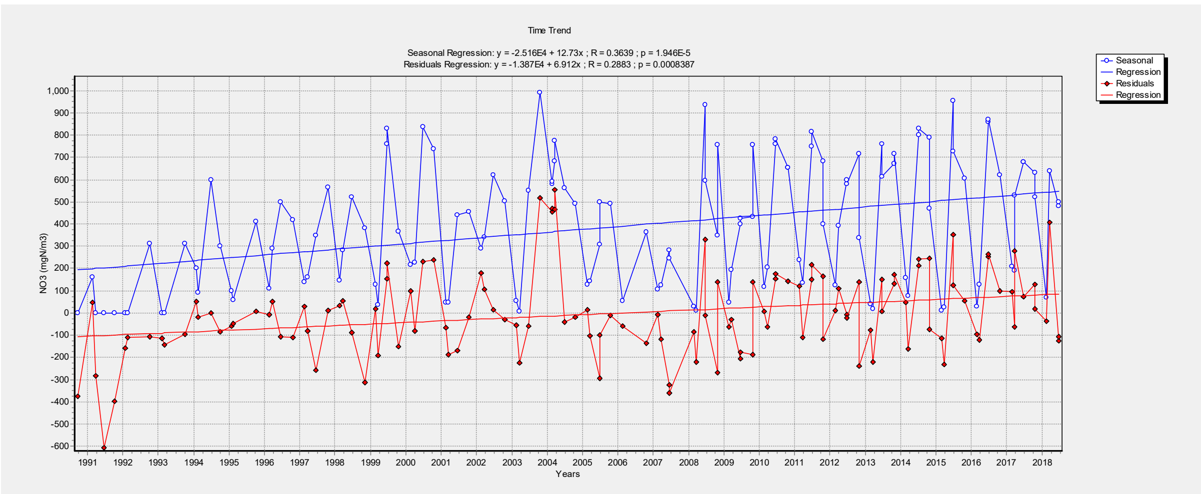

Time Trend
Seasonal Regression: y = -802.8 + 0.405x ; R = 0.0846 ; p = 0.2642
Residuals Regression: y = -681.8 + 0.3395x ; R = 0.07227 ; p = 0.3405
TSS (g/m3)
Years
Seasonal
Regression
Residuals
Regression

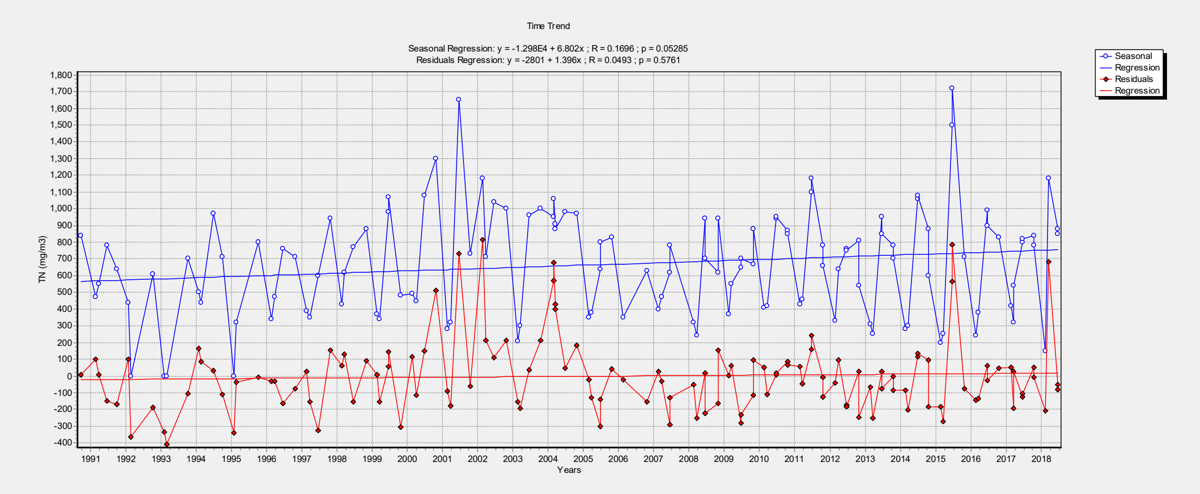

Time Trend
Seasonal Regression: y = 57.05 + -0.02057x ; R = -0.04171 ; p = 0.6624
Residuals Regression: y = -21.91 + 0.01093x ; R = 0.0672 ; p = 0.4815
Temperature (° C)
Years
Seasonal
Regression
Residuals
Regression

L2 – Nutrients

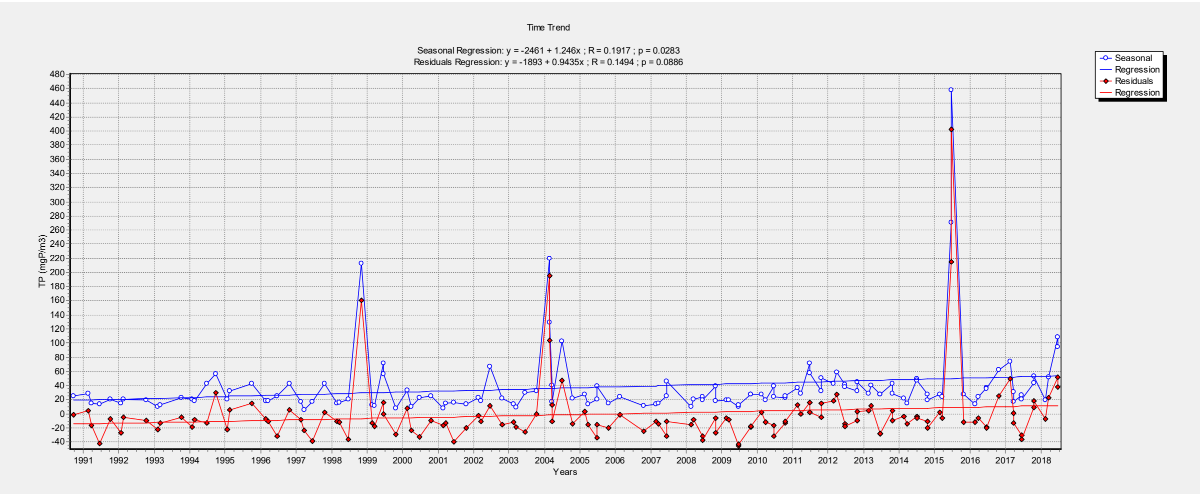








Time Trend
Seasonal Regression: y = -1.298E4 + 6.802x ; R = 0.1696 ; p = 0.05285
Residuals Regression: y = -2801 + 1.396x ; R = 0.0493 ; p = 0.5761
Seasonal
Regression
Residuals
Regression
TN (mg/m3)
Years



Time Trend
Seasonal Regression: y = -2461 + 1.246x ; R = 0.1917 ; p = 0.0283
Residuals Regression: y = -1893 + 0.9435x ; R = 0.1494 ; p = 0.0886
Seasonal
Regression
Residuals
Regression
TP (mgP/m3)
Years

HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd)

Date From: 01/01/1990 **Date To:** 31/12/2018

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.1 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	11.7	-43.3	-38.7
01-Jan-1991 - 31-Mar-1991	11.58	5.1	4.6
01-Jan-1992 - 30-Mar-1992	9.94	5.6	5.7
01-Jan-1993 - 31-Mar-1993	9.4	-11.2	-11.7
01-Jan-1994 - 31-Mar-1994	8.72	-35.2	-38.7
01-Jan-1995 - 31-Mar-1995	11.58	30.7	27.6
01-Jan-1996 - 30-Mar-1996	9.29	8.9	9.4
01-Jan-1997 - 31-Mar-1997	8.82	-24.8	-27.0
01-Jan-1998 - 31-Mar-1998	8.53	-0.6	-0.7
01-Jan-1999 - 31-Mar-1999	13.14	-7.9	-6.4
01-Jan-2000 - 04-Apr-2000	10.23	5.4	5.3
01-Jan-2001 - 31-Mar-2001	10.78	-1.1	-1.1
01-Jan-2002 - 31-Mar-2002	8.86	1.4	1.5
01-Jan-2003 - 31-Mar-2003	10.3	-39.2	-38.7
01-Jan-2005 - 31-Mar-2005	9.03	19.0	20.5
01-Jan-2006 - 31-Mar-2006	9.51	19.4	20.2
01-Jan-2007 - 31-Mar-2007	10.04	5.8	5.8
01-Jan-2008 - 30-Mar-2008	9.73	-6.5	-6.6
01-Jan-2009 - 31-Mar-2009	10.36	-9.4	-9.2
01-Jan-2010 - 31-Mar-2010	8.96	-20.4	-22.1
01-Jan-2011 - 31-Mar-2011	10.63	9.5	9.2
01-Jan-2012 - 30-Mar-2012	9.73	-14.8	-15.2
01-Jan-2013 - 31-Mar-2013	10.07	6.4	6.4
01-Jan-2014 - 31-Mar-2014	11.0	15.0	14.1
01-Jan-2015 - 31-Mar-2015	9.74	1.6	1.6
01-Jan-2016 - 30-Mar-2016	9.52	3.1	3.3
01-Jan-2017 - 31-Mar-2017	9.39	0.8	0.9
01-Jan-2018 - 31-Mar-2018	11.91	-35.7	-31.4
Average	**10.09**	**-4.0**	**-4.0**

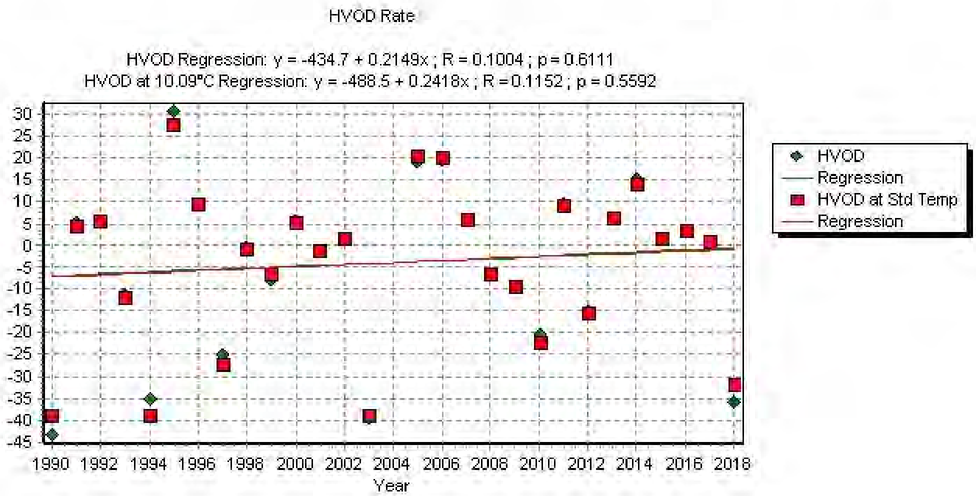
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L2 (Tangahoe Valley Rd)

Date From: 01/01/1990 **Date To:** 31/12/2018

Analysis Period	Average	Observed DO	Observed Rate Corrected to 10.1 °C (mg/m3/day)



LAKE ROTORANGI

L2 1990-2019 (1 Jan 1990 - 31 Dec 2018)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.06	(0.00)	(0.94)	(1.40)	(0.24)			
Average Over Period	3.20	(2.60)	(38.30)	(670.00)	(-3.98)			
Percent Annual Change (%/Year)	**1.88**	**0.00**	**0.00**	**0.00**	**0.00**	**0.38**	**0.38**	**0.37**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	7.20	1.25	25.00	840.00	4.40	5.27	4.30	5.19	4.79	0.26			
Jan 1991 - Dec 1991	2.17	2.34	19.50	610.00	3.08	4.53	3.98	4.77	4.09	0.38			
Jan 1992 - Dec 1992	3.07	1.92	18.33	350.00	3.46	4.77	3.91	4.05	4.04	0.27			
Jan 1993 - Dec 1993	2.47	3.82	15.00	233.33	3.22	3.93	3.65	3.52	3.58	0.15			
Jan 1994 - Dec 1994	1.33	2.29	34.25	655.00	2.53	4.56	4.70	4.87	4.16	0.55			
Jan 1995 - Dec 1995	2.23	2.71	31.33	373.33	3.11	4.35	4.59	4.13	4.04	0.33			
Jan 1996 - Dec 1996	3.08	2.52	26.00	570.00	3.46	4.44	4.35	4.69	4.23	0.27			
Jan 1997 - Dec 1997	1.32	2.35	20.50	570.00	2.53	4.53	4.05	4.69	3.95	0.49			
Jan 1998 - Dec 1998	2.15	2.06	66.00	675.00	3.06	4.68	5.53	4.91	4.55	0.53			
Jan 1999 - Dec 1999	2.74	3.77	31.80	648.00	3.33	3.95	4.61	4.85	4.18	0.34			
Jan 2000 - Dec 2000	3.85	2.57	22.75	830.00	3.71	4.42	4.18	5.18	4.37	0.31			
Jan 2001 - Dec 2001	2.43	3.87	13.00	745.00	3.20	3.92	3.47	5.04	3.90	0.40			
Jan 2002 - Dec 2002	3.15	2.14	32.50	982.50	3.49	4.64	4.63	5.40	4.54	0.39			
Jan 2003 - Dec 2003	1.77	2.98	21.25	617.50	2.85	4.24	4.09	4.79	3.99	0.41			
Jan 2004 - Dec 2004	3.90	0.93	88.50	958.33	3.72	5.62	5.90	5.36	5.15	0.49			
Jan 2005 - Dec 2005	2.94	2.50	23.40	600.00	3.41	4.45	4.22	4.75	4.21	0.29			
Jan 2006 - Dec 2006	2.50	2.55	17.50	490.00	3.23	4.43	3.85	4.49	4.00	0.29			
Jan 2007 - Dec 2007	5.27	2.34	28.17	730.00	4.05	4.53	4.45	5.01	4.51	0.20			
Jan 2008 - Dec 2008	2.15	3.01	21.67	626.67	3.06	4.23	4.12	4.81	4.05	0.36			
Jan 2009 - Dec 2009	4.38	3.30	19.17	636.67	3.85	4.11	3.96	4.83	4.19	0.22			
Jan 2010 - Dec 2010	4.32	2.21	26.33	740.00	3.84	4.60	4.37	5.03	4.46	0.25			
Jan 2011 - Dec 2011	3.50	3.87	46.17	768.33	3.60	3.92	5.08	5.08	4.42	0.39			
Jan 2012 - Dec 2012	2.90	2.16	43.00	638.33	3.39	4.63	4.99	4.83	4.46	0.36			
Jan 2013 - Dec 2013	4.15	2.91	32.83	640.00	3.79	4.27	4.65	4.84	4.39	0.23			
Jan 2014 - Dec 2014	3.13	3.06	30.17	700.00	3.48	4.21	4.54	4.95	4.29	0.31			
Jan 2015 - Dec 2015	3.83	2.16	161.40	876.00	3.70	4.63	6.67	5.25	5.06	0.62			
Jan 2016 - Dec 2016	3.20	2.77	34.40	668.00	3.50	4.33	4.70	4.89	4.36	0.31			
Jan 2017 - Dec 2017	3.85	2.41	37.86	645.71	3.71	4.50	4.83	4.85	4.47	0.27			
Jan 2018 - Dec 2018	6.10	1.85	68.25	765.00	4.21	4.81	5.57	5.07	4.92	0.28			
Averages	**3.28**	**2.57**	**36.41**	**661.47**	**3.45**	**4.47**	**4.55**	**4.83**	**4.32**	**0.07**	**0.02**	**0.01**	**0.0276**

SUMMARY:

PAC = 0.38 ± 0.38 % per year
P-Value = 0.37

TLI Value = 4.32 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.0276

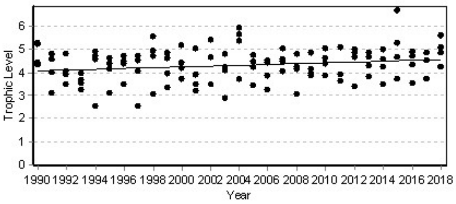
ASSESSMENT:

Eutrophic
No Change

The guide used in the PAC average P-Value evaluation is

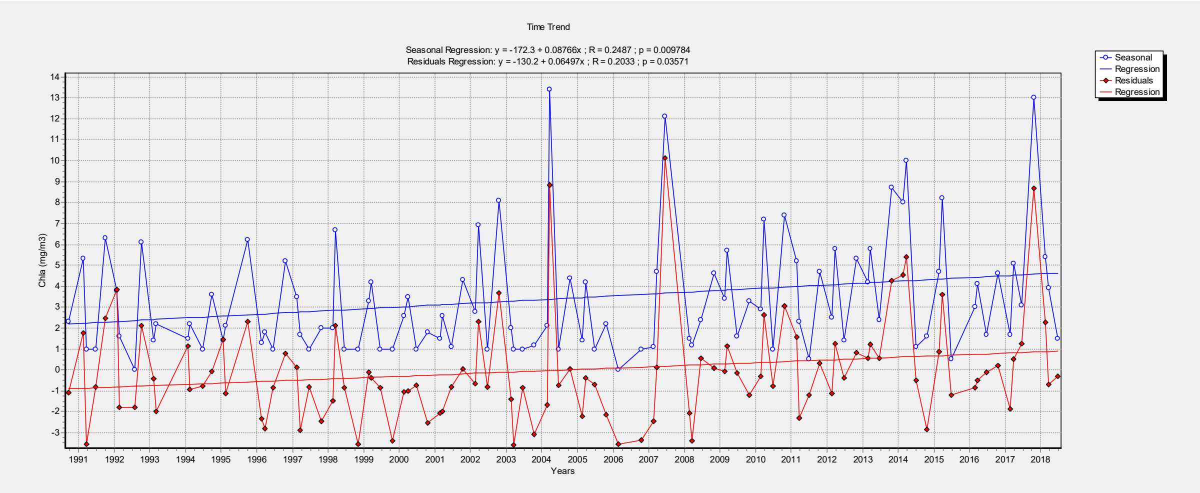
P-Value Range	Interpretation
P ≤ 0.1	Definite Change
0.1 < P ≤ 0.2	Probable Change
0.2 < P ≤ 0.3	Possible Change
0.3 < P	No Change

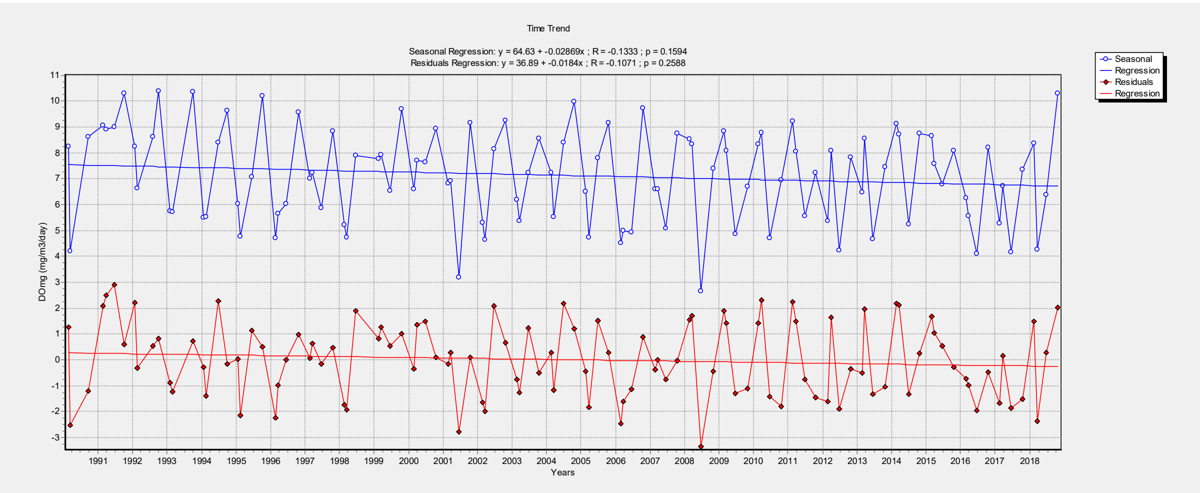
TLI Trend: y = -30.59 + 0.01742x ; R = 0.2046 ; p = 0.02756

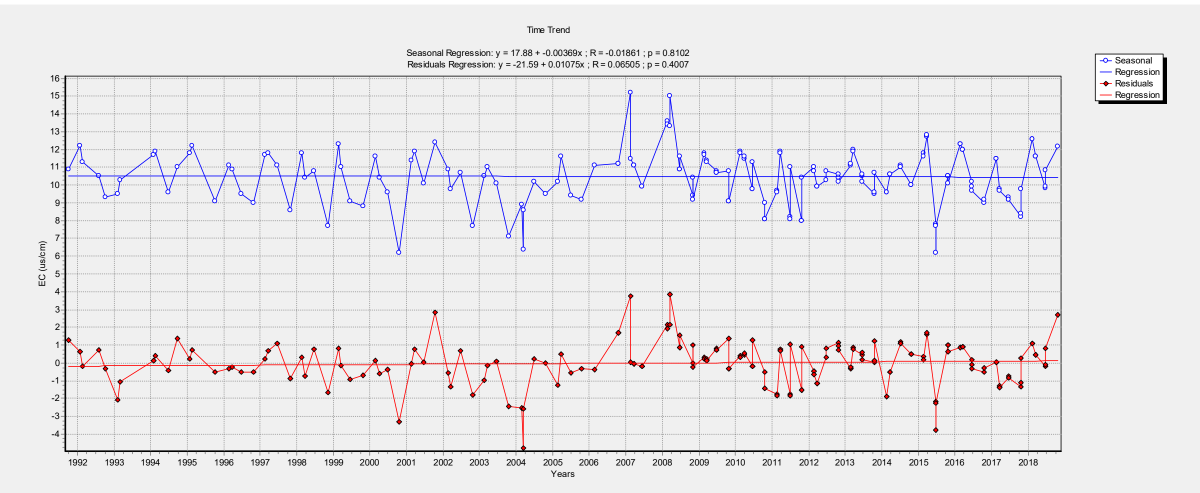


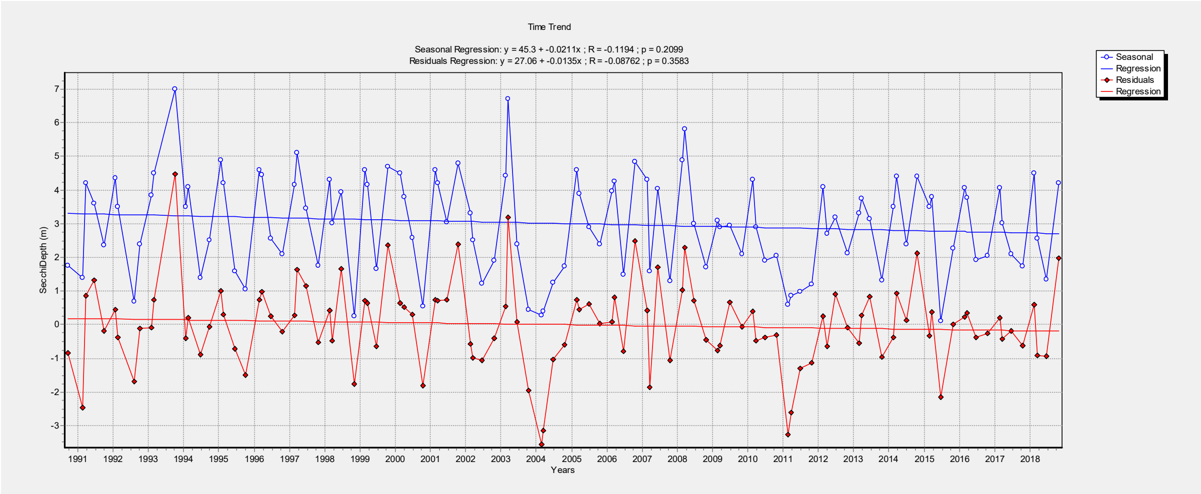
Appendix 4

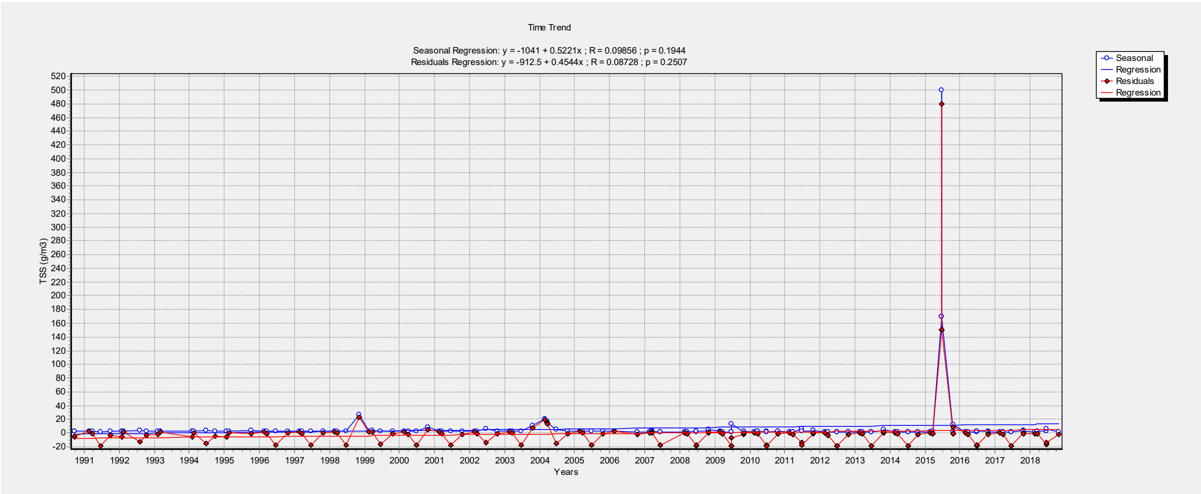
L3 – Physical parameters

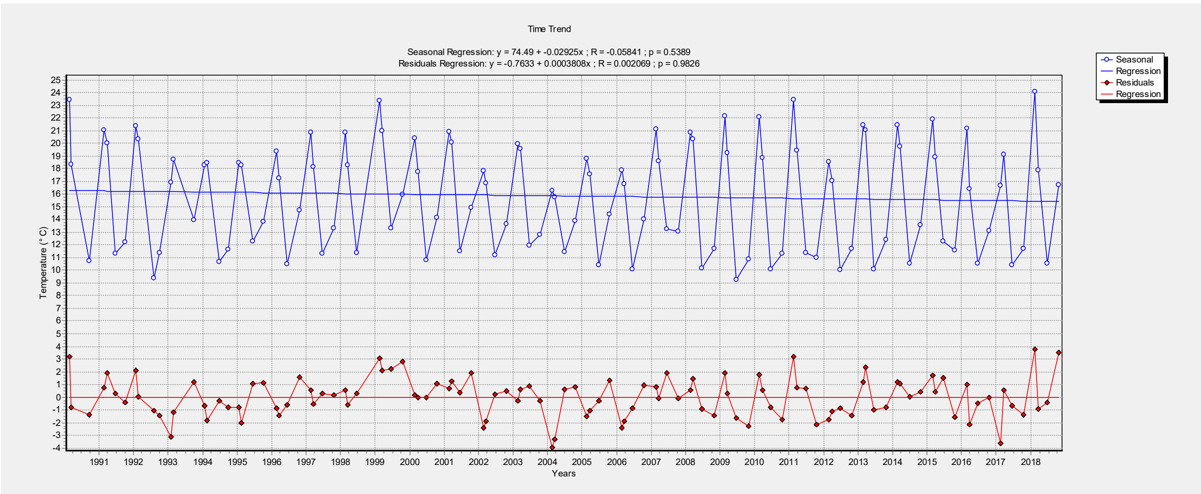




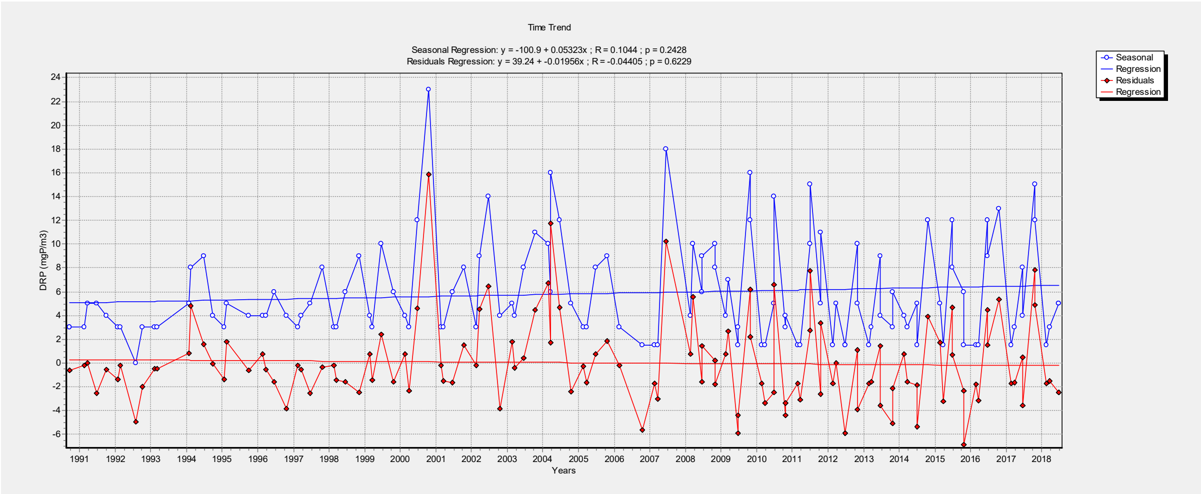


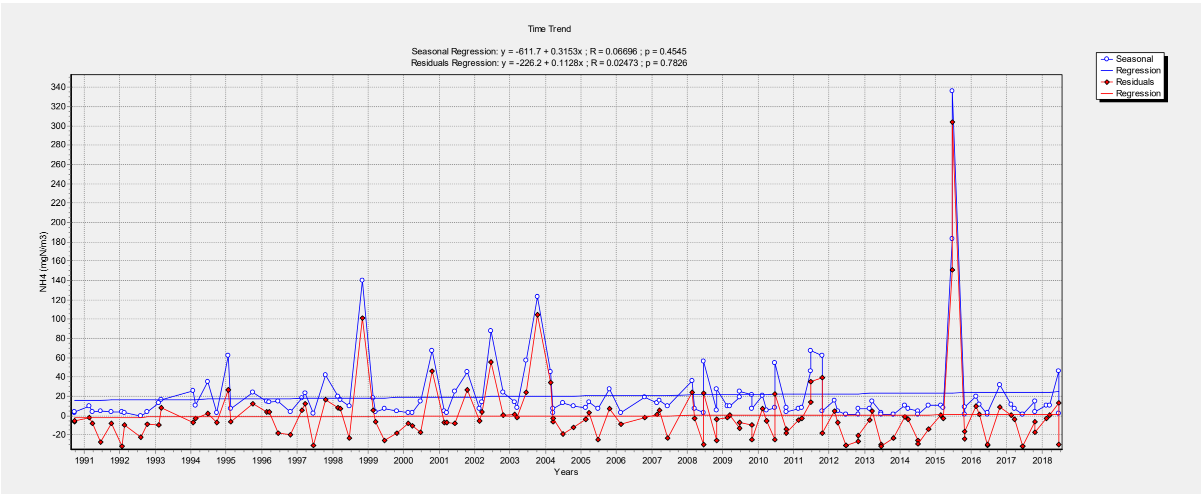

Time Trend
Seasonal Regression: y = 45.3 + -0.0211x ; R = -0.1194 ; p = 0.2099
Residuals Regression: y = 27.06 + -0.0135x ; R = -0.08762 ; p = 0.3583
Secchi Depth (m)
Years
Seasonal
Regression
Residuals
Regression

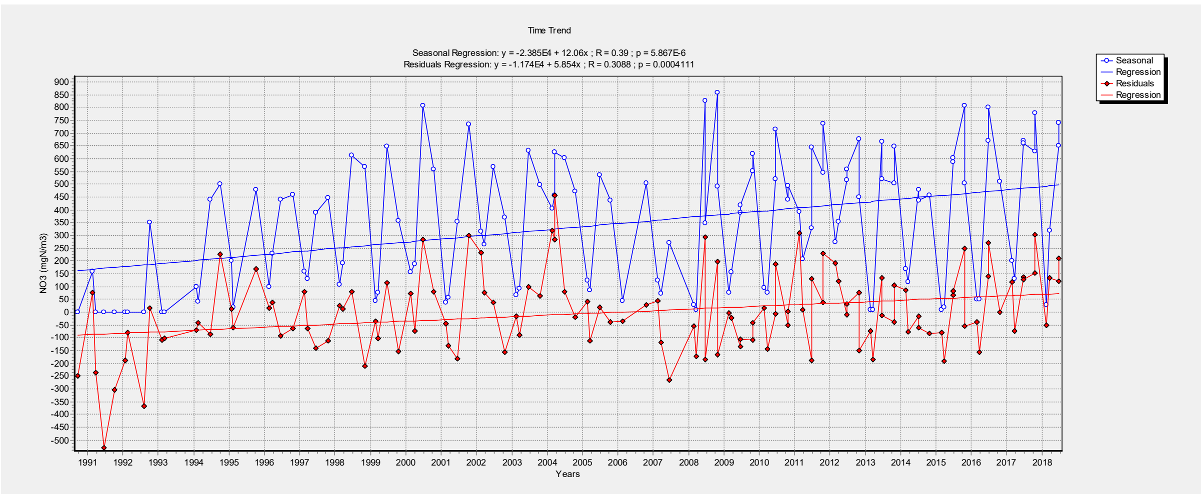

Time Trend
Seasonal Regression: y = -1041 + 0.5221x ; R = 0.09856 ; p = 0.1944
Residuals Regression: y = -912.5 + 0.4544x ; R = 0.08728 ; p = 0.2507
TSS (g/m3)
Years
Seasonal
Regression
Residuals
Regression

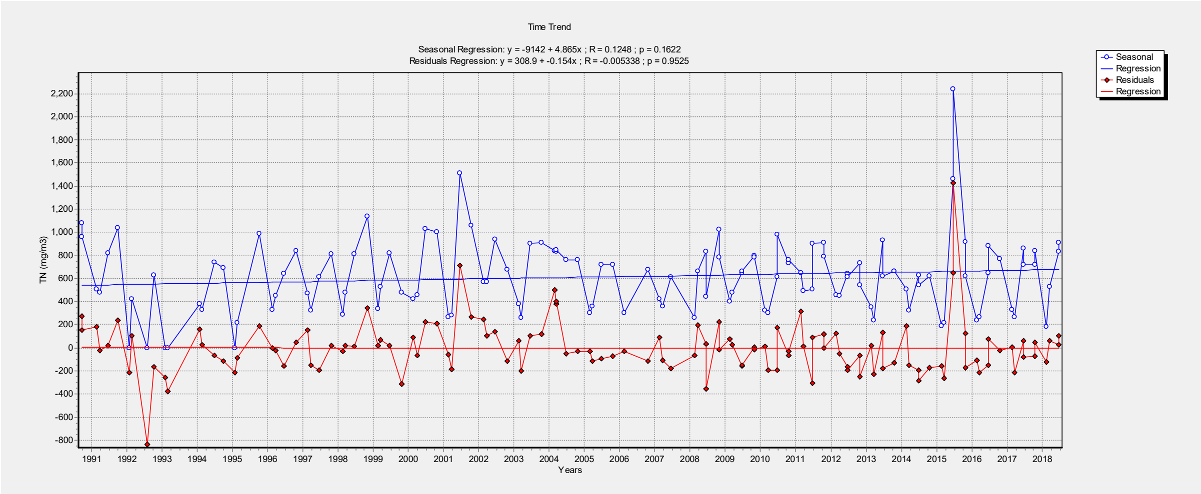

Time Trend
Seasonal Regression: y = 74.49 + -0.02925x ; R = -0.05841 ; p = 0.5389
Residuals Regression: y = -0.7633 + 0.0003808x ; R = 0.002069 ; p = 0.9826
Temperature (° C)
Years
Seasonal
Regression
Residuals
Regression

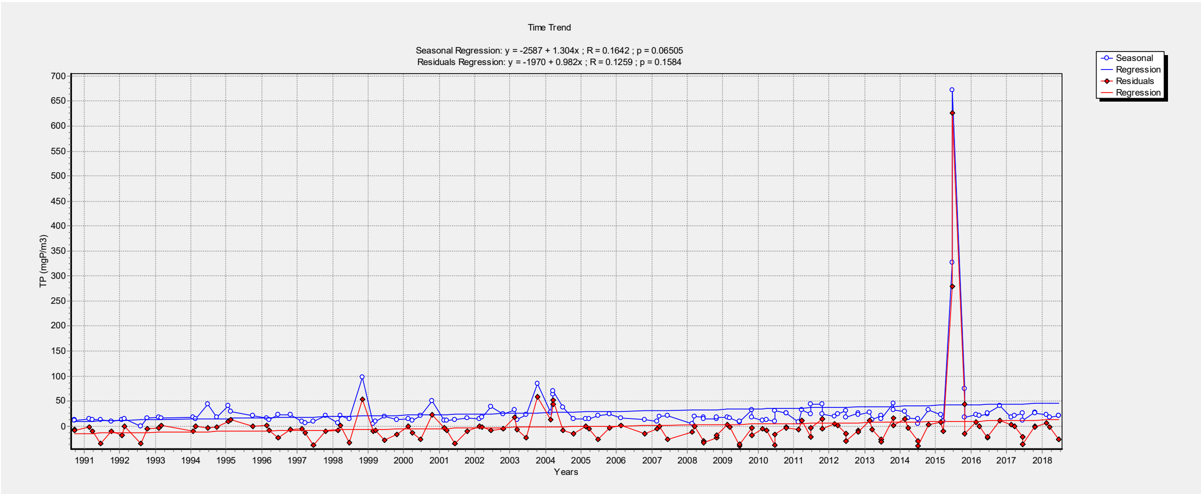
L3 – Nutrients








Time Trend
Seasonal Regression: y = -9142 + 4.865x ; R = 0.1248 ; p = 0.1622
Residuals Regression: y = 308.9 + -0.154x ; R = -0.005338 ; p = 0.9525
TN (mg/m3)
Years
Seasonal
Regression
Residuals
Regression


Time Trend
Seasonal Regression: y = -2587 + 1.304x ; R = 0.1642 ; p = 0.06505
Residuals Regression: y = -1970 + 0.982x ; R = 0.1259 ; p = 0.1584
TP (mgP/m3)
Years
Seasonal
Regression
Residuals
Regression

HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2018

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.7 °C (mg/m3/day)
01-Jan-1990 - 31-Mar-1990	9.31	45.4	46.8
01-Jan-1991 - 31-Mar-1991	11.6	19.4	17.0
01-Jan-1992 - 30-Mar-1992	9.76	14.6	14.6
01-Jan-1993 - 31-Mar-1993	9.4	8.8	9.0
01-Jan-1994 - 31-Mar-1994	8.62	16.1	17.4
01-Jan-1995 - 31-Mar-1995	10.62	49.8	46.8
01-Jan-1996 - 30-Mar-1996	8.59	45.7	49.5
01-Jan-1997 - 31-Mar-1997	8.51	29.1	31.7
01-Jan-1998 - 31-Mar-1998	8.09	11.8	13.2
01-Jan-1999 - 31-Mar-1999	13.49	35.3	27.2
01-Jan-2000 - 04-Apr-2000	10.0	5.8	5.7
01-Jan-2001 - 31-Mar-2001	11.39	34.0	30.3
01-Jan-2002 - 31-Mar-2002	8.6	16.5	17.8
01-Jan-2003 - 31-Mar-2003	9.47	-0.8	-0.8
01-Jan-2005 - 31-Mar-2005	8.86	55.0	58.5
01-Jan-2006 - 31-Mar-2006	9.34	18.8	19.4
01-Jan-2007 - 31-Mar-2007	10.33	4.5	4.3
01-Jan-2008 - 30-Mar-2008	9.25	16.0	16.6
01-Jan-2009 - 31-Mar-2009	9.76	29.9	29.8
01-Jan-2010 - 31-Mar-2010	8.98	-15.6	-16.4
01-Jan-2011 - 31-Mar-2011	9.88	38.4	38.1
01-Jan-2012 - 30-Mar-2012	8.78	4.0	4.3
01-Jan-2013 - 31-Mar-2013	9.78	19.7	19.6
01-Jan-2014 - 31-Mar-2014	10.92	2.8	2.6
01-Jan-2015 - 31-Mar-2015	9.51	2.8	2.8
01-Jan-2016 - 30-Mar-2016	9.67	2.5	2.5
01-Jan-2017 - 31-Mar-2017	10.0	21.1	20.7
01-Jan-2018 - 31-Mar-2018	10.24	38.6	37.3
Average	**9.74**	**20.4**	**20.2**

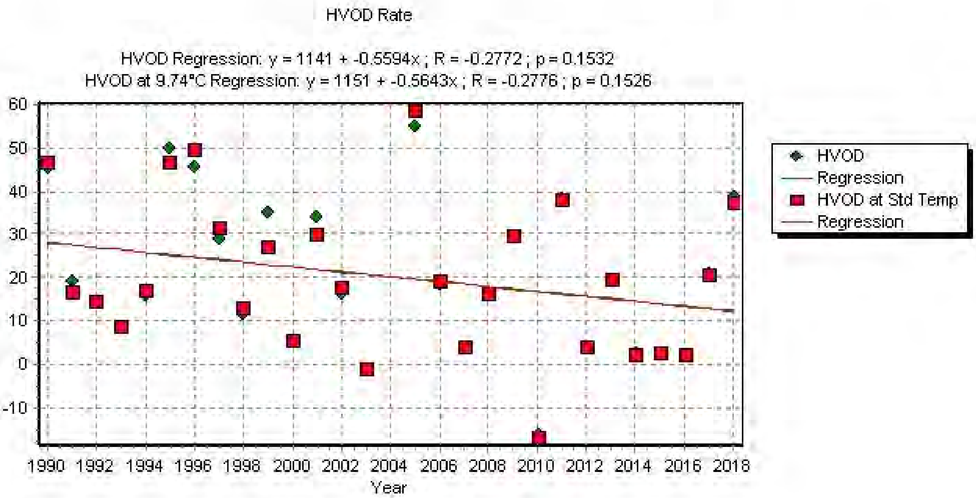
HVOD Analysis

Lake: LAKE ROTORANGI

Stations: L3 (Dam)

Date From: 01/01/1990 **Date To:** 31/12/2018

Analysis Period	Average	Observed DO	Observed Rate Corrected to 9.7 °C (mg/m3/day)



LAKE ROTORANGI

L3 1990-2019 (1 Jan 1990 - 31 Dec 2018)

Percent Annual Change (PAC)

Lake	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	HVOD (mg/m3/day)	Avg PAC	Std Err	P-Value
Change - Units Per Year	0.06	(-0.01)	(0.98)	(-0.15)	(-0.56)			
Average Over Period	3.42	(3.00)	(29.28)	(616.30)	(20.23)			
Percent Annual Change (%/Year)	**1.75**	**0.00**	**0.00**	**0.00**	**0.00**	**0.35**	**0.35**	**0.37**

Burns Trophic Level Index Values and Trends

Period	Chla (mg/m3)	SD (m)	TP (mgP/m3)	TN (mg/m3)	TLc	TLs	TLp	TLn	TLI Average	Std. Err. TL av	TLI Trend units/yr	Std. Err. TLI trend	P-Value
Jan 1990 - Dec 1990	2.30	1.75	12.00	1,020.00	3.14	4.88	3.37		3.80	0.55			
Jan 1991 - Dec 1991	3.40	2.89	12.25	712.50	3.57	4.28	3.40		3.75	0.27			
Jan 1992 - Dec 1992	2.87	2.74	10.75	262.50	3.38	4.34	3.23		3.65	0.35			
Jan 1993 - Dec 1993	1.80	5.12	17.00	0.00	2.87	3.56	3.81		3.41	0.28			
Jan 1994 - Dec 1994	2.07	2.87	23.25	535.00	3.03	4.28	4.21		3.84	0.41			
Jan 1995 - Dec 1995	3.23	2.94	29.67	403.33	3.51	4.26	4.52		4.10	0.30			
Jan 1996 - Dec 1996	2.32	3.42	18.50	565.00	3.15	4.07	3.92		3.71	0.28			
Jan 1997 - Dec 1997	2.05	3.61	11.50	552.50	3.01	4.00	3.32		3.44	0.29			
Jan 1998 - Dec 1998	2.67	2.89	34.50	680.00	3.31	4.28	4.71		4.10	0.42			
Jan 1999 - Dec 1999	2.37	3.77	11.50	542.50	3.17	3.95	3.32		3.48	0.24			
Jan 2000 - Dec 2000	2.22	2.86	24.25	727.50	3.10	4.29	4.26		3.88	0.39			
Jan 2001 - Dec 2001	2.38	4.16	12.50	780.00	3.17	3.83	3.42		3.47	0.19			
Jan 2002 - Dec 2002	4.70	2.23	23.50	690.00	3.93	4.59	4.22		4.25	0.19			
Jan 2003 - Dec 2003	1.30	3.49	38.00	612.50	2.51	4.05	4.83		3.80	0.68			
Jan 2004 - Dec 2004	6.86	0.92	42.40	808.00	4.34	5.63	4.97		4.98	0.37			
Jan 2005 - Dec 2005	2.20	3.45	18.25	525.00	3.09	4.06	3.90		3.68	0.30			
Jan 2006 - Dec 2006	0.50	3.64	14.00	490.00	1.46	3.99	3.56		3.00	0.78			
Jan 2007 - Dec 2007	4.75	2.81	21.00	592.50	3.94	4.31	4.08		4.11	0.11			
Jan 2008 - Dec 2008	2.43	3.85	14.33	665.00	3.20	3.92	3.59		3.57	0.21			
Jan 2009 - Dec 2009	3.50	2.76	17.00	628.33	3.60	4.33	3.81		3.91	0.22			
Jan 2010 - Dec 2010	4.63	2.79	19.00	616.67	3.91	4.32	3.95		4.06	0.13			
Jan 2011 - Dec 2011	3.17	0.91	29.17	708.33	3.49	5.64	4.50		4.54	0.62			
Jan 2012 - Dec 2012	3.75	3.03	23.00	571.67	3.68	4.22	4.19		4.03	0.18			
Jan 2013 - Dec 2013	5.27	2.88	25.67	576.67	4.05	4.28	4.33		4.22	0.09			
Jan 2014 - Dec 2014	5.18	3.68	19.60	524.00	4.03	3.98	3.99		4.00	0.02			
Jan 2015 - Dec 2015	4.47	2.42	187.17	941.67	3.87	4.49	6.85		5.07	0.91			
Jan 2016 - Dec 2016	3.35	2.95	26.20	562.00	3.55	4.25	4.36		4.05	0.25			
Jan 2017 - Dec 2017	5.72	2.73	21.00	623.33	4.14	4.35	4.08		4.19	0.08			
Jan 2018 - Dec 2018	3.60	3.15	20.00	612.50	3.63	4.17	4.02		3.94	0.16			
Averages	**3.28**	**2.99**	**26.79**	**604.45**	**3.41**	**4.30**	**4.09**		**3.93**	**0.07**	**0.02**	**0.01**	**0.0141**

SUMMARY:

PAC = 0.35 ± 0.35 % per year
P-Value = 0.37

TLI Value = 3.93 ± 0.07 TLI units
TLI Trend = 0.02 ± 0.01 TLI units per year
P-Value = 0.0141

ASSESSMENT:

Mesotrophic
No Change

The guide used in the PAC average P-Value evaluation is

P-Value Range	Interpretation
$P \leq 0.1$	Definite Change
$0.1 < P \leq 0.2$	Probable Change
$0.2 < P \leq 0.3$	Possible Change
$0.3 < P$	No Change